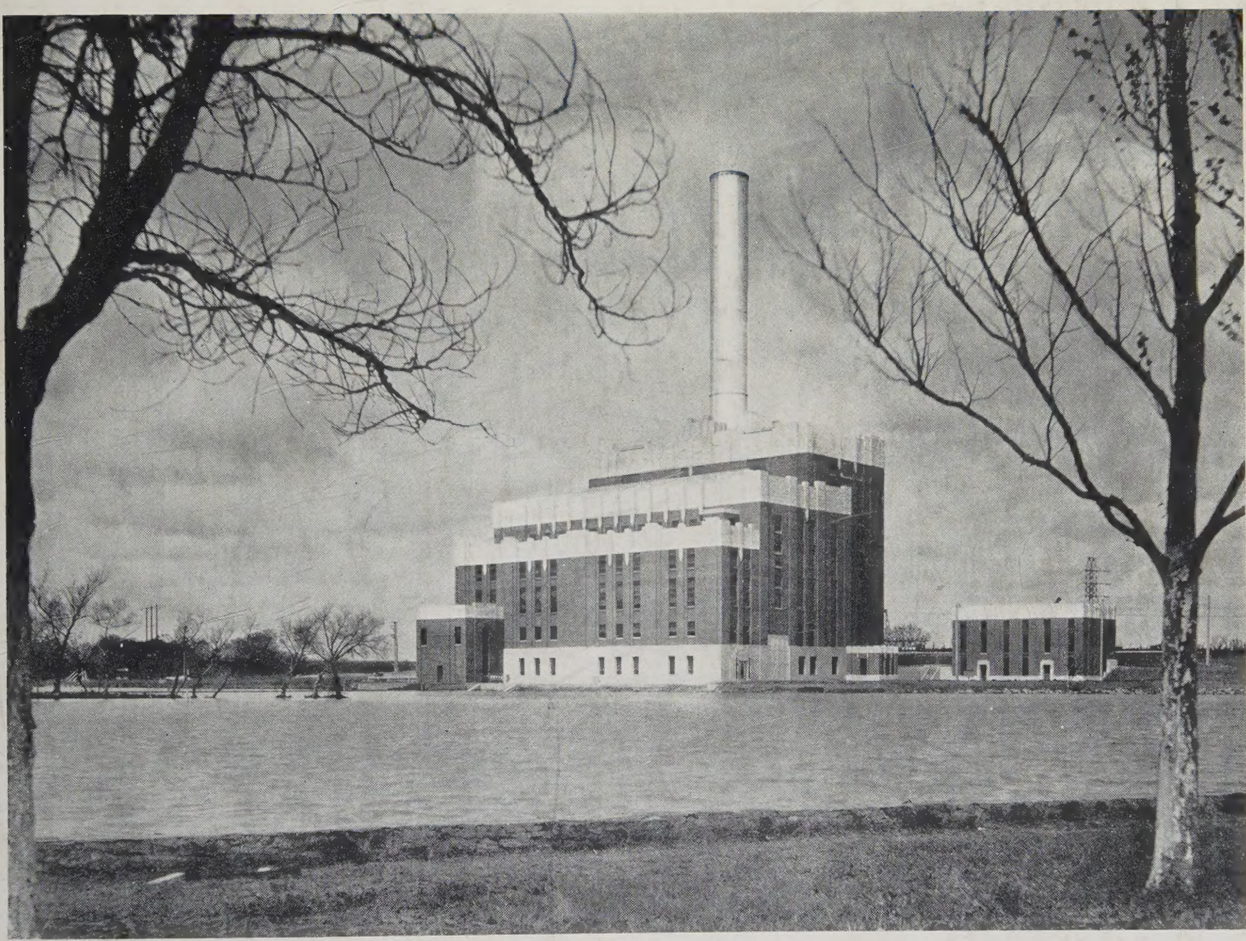
Electrical Engineering

April
1935



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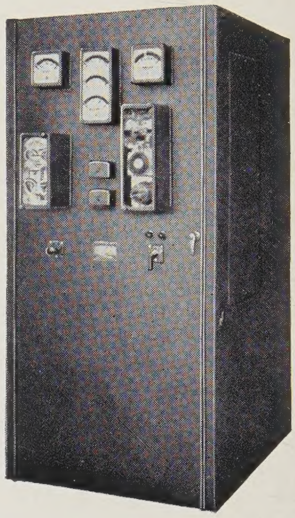

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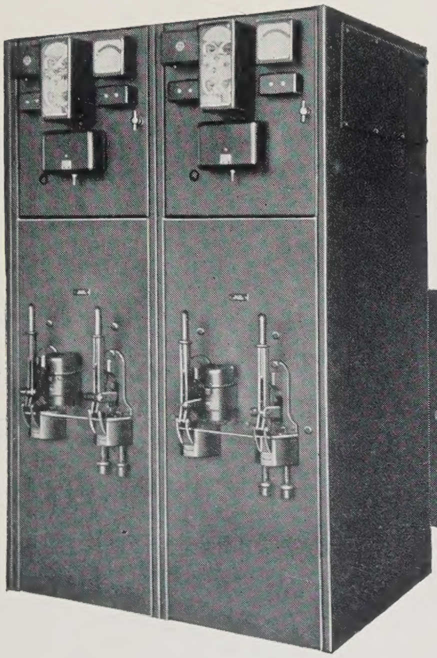

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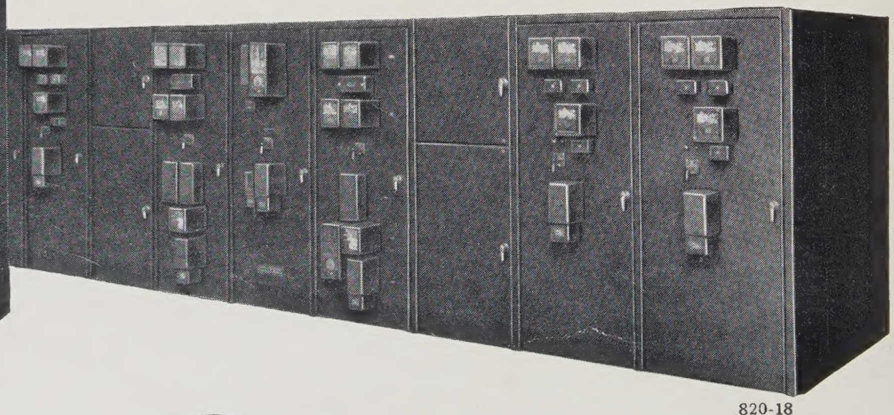

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Front Cover

Arthur F. Huey generating station on Bell Isle Lake, Oklahoma City, Okla., near the scene of the Institute's forthcoming South West District meeting. This 30,000 kw station is the most modern in the southwest. Gas from the nearby Oklahoma City fields is used as fuel.

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Engineering Education as a Preparation for Any Life Work

By J. Allen Johnson, President A.I.E.E.

In our present day engineering civilization, is there a logical basis for the thesis that an engineering education is a good preparation for any life work? President Johnson says there is, and in this article gives strong supporting reasons for his contention. He concludes that a broad basic engineering education "which opens the mind and shows it how nature itself does its work, and teaches it to apply that knowledge through original thinking to the specific problems of one's life work, is a preparation for that life work which has, and in the very nature of things can have, no equal."

ON AN occasion of this kind* it seems clear that the proposition which I am expected to support in this brief talk is that an engineering education is a *good* preparation for any life work, possibly that it is superior to any other preparation or at least any other kind of education as such a preparation.

What is our criterion to be? Is the benefit of an engineering education to be assumed to inure to the individual concerned or to the social system as a whole? I think we must cling, in this discussion, to the criterion of advantage to the individual concerned. That is to say, the question the young man will ask and which we must try to answer is "Will an engineering education be the best preparation to help *me* accomplish *my* life's work?"

It now seems pertinent to inquire what we mean by "preparation" for a life work. Obviously there are many careers for which an engineering education could not be a *complete* preparation. In fact, no formal education can possibly be a *complete* preparation for any career, because every career is, in a very real sense, its own preparation for itself. All past experience is preparation for what is to come and education, in its broadest sense, is continuous from the cradle to the grave. So when we say "preparation" we must, I think, construe the word in the sense of "foundation."

"Education" and "Training" Not Synonomous

Here, I think, we must begin to differentiate clearly between "education" and "training." You will note that my subject says "engineering education" not "technical training." This differentiation, indeed, is implicit in the motto on the "Tech" seal, "Lehr and Kunst"—knowledge and skill—hence education for the acquisition of knowledge and training for the acquirement of skill, that is, the application of knowledge to the solution of practical problems. Both are necessary parts of the preparation for any life work. The 2 words are often loosely used synonymously, but they are far from synonymous. Education is a divergent or broadening process, while training is a convergent or narrowing process. Education is directed toward the attainment of a knowledge of many things *and of the relationships between them.* Training is directed toward the practical application of possibly only a single item of knowledge with no consideration whatever of its relationship to others. Education may be likened to a climbing up on a high mountain whence the surrounding terrain may be observed as a whole. Intellectually it implies the loosening and casting off from the mind and spirit of the shackles of tradition and dogma and prejudice and habit, and helping the mind to expand and grow and encompass ever widening and deepening comprehensions of the unity of the universe, and of the relationships between its component parts and processes.

In this world where each of us must make a living as well as live a life, training for the performance of some specific task is a practical necessity. One can, indeed, earn a living with training alone. Millions do so. Indeed, many highly trained specialists in our modern industrial society make good livings, but training without education can never result in the highest achievement.

I am entirely aware that there is nothing new or revolutionary in what I have so far said. The idea that an "education," in the sense above defined, should constitute the foundation upon which to build one's life work is not new. In fact, 35 years ago, when I was preparing for college, it used to be urged that a liberal arts education ought to precede technical training, and this argument may still be advanced in some quarters for aught I know. Here and now, however, the shoe is on the other foot and we are investigating the thesis that an *engineering* education should constitute the base for *any* kind of training. Is there a logical reason for this change? I think there is.

An Engineering Civilization

The civilization in which we are now living is an engineering civilization. Scientists, inventors, and engineers have made it, and engineers keep it going. From our first breath to our descent to the grave we are in almost continuous contact with some product or process of engineering. This was not always so. In simple and more primitive times such machines as were used were fashioned largely by trial and error. It is only within the last 100 years that mechanical, electrical, and chemical engineering have really existed at all and only within the last 50 years that they have become the overwhelmingly dominant

* One of the 4 addresfes comprising a symposium on engineering education delivered at the annual joint meeting of New York and New Jersey alumni of Worcester (Mass.) Polytechnic Institute held in New York, N. Y., Dec. 6, 1934; published by the Alumni Association of the Worcester Polytechnic Institute in a supplement to the *Journal* of W.P.I., Jan. 1935.

factors that they now are in our daily lives. In view of this revolutionary change it is not only proper but imperative that we reconsider the question of what is the best preparation for a life work.

How does this changed situation affect, let us say, the other professions? Take, for instance, the law. A large proportion of the civil cases in our courts involve the many technical devices of this engineering civilization. I have listened to lawyers trying such cases whose ignorance of the simplest natural laws and physical relationships was pitiful; and on the other hand I have read judicial decisions proclaiming such a clear and exact knowledge of fundamental engineering facts and relationships on the part of the judges who wrote them that their mere perusal by an engineer was an intellectual treat. Is it possible that the *engineering education* possessed by these judges—however attained—was the reason for their elevation from the bar to the bench? I think it highly probable that it was at least an important factor.

Or take the ministry. In this technical age a minister who is ignorant of the fundamental laws of physical nature is surely under a severe handicap. The minister who is not accurately informed on such matters and attempts to interpret the scriptures today without benefit of modern scientific knowledge is likely to find himself greatly embarrassed. Indeed, when a modern scientist like Sir James Jeans says, as he does in his "The Mysterious Universe," "Today there is a wide measure of agreement—that the stream of knowledge is heading toward a non-mechanical reality; the universe begins to look more like a great thought than like a great machine. Mind no longer appears as an accidental intruder into the realm of matter; we are beginning to suspect that we ought rather to hail it as the creator and governor of the realm of matter"—and again "We discover that the universe shows evidence of a designing or controlling power that has something in common with our own individual minds"—when, I say, a great scientist makes such a statement as this, it appears that modern science and modern religion are not so far apart, and the modern minister surely cannot get along without a pretty accurate knowledge of modern science.

Obviously, in the short time at my disposal, I cannot take up one at a time every possible "life work" and individually argue the value of an engineering education as a foundation for it. Somewhere we must start to generalize. Now, if there is one thing that the progress of scientific knowledge has demonstrated it is the *unity* of nature. I like to think of it in these terms, that no matter where you may dip into nature's ocean of information or just what set of simultaneous equations you may find in your net, *you will always get the same value of X*. For instance, the velocity of light in free space, whether approached from the optical or from the electrical angle, yields the same answer. Planck's constant, *H*, keeps bobbing up, always with the same value. Newton's laws of motion are all-embracive. Nature's fundamental ways of doing things are universal. They may appear in different guises, but the same old fundamental laws and processes and relationships bob up serenely, and may be recognized by those who have learned to understand nature's language wherever they appear.

Same Fundamental Laws Govern Both People and Things

All "life works" have to do with things and people. Some, like engineering, have to do more with things; others like the law and the ministry, more with people. But if it is true that nature's ways of doing things are universal, then must it not be true that the same fundamental laws which govern the behavior of *things* also govern the behavior of *people?* Admittedly it is difficult to prove this for 2 reasons: first, because there is no way of accurately measuring the magnitude of the spiritual forces which act on people, nor of their effects; and second, because of the multiplicity of such forces which act simultaneously, thus making it difficult to identify the forces with their effects. But, nevertheless, qualitatively human forces and their effects can often be identified, and their operation interpreted and more clearly understood by comparison with analogous physical laws. For instance, suppose we observe that if some one criticizes some task which we have performed we get angry in proportion to the degree of imperfection in our performance of the task. In other words, the poorer the job we have done the madder we get when any one criticizes it. We might express this in an equation something like this:

$$\text{Anger} = (f)\,\frac{\text{criticism}}{\text{excellence of performance}}$$

Now if in order to illuminate and better understand this observation we seek a physical analogy for this expression, we may find it in the thermal realm in the expression

$$\text{Temperature rise} = (f)\,\frac{\text{heat added}}{\text{specific heat}}$$

or in the electrical realm we may similarly write

$$\text{Potential} = (f)\,\frac{\text{charge}}{\text{capacitance}}$$

Thus it appears by analogy that "excellence of performance" might be defined as "ability to absorb criticism," and "anger" as merely the index of the relationship. Further study would doubtless reveal even more interesting implications. Perhaps all emotion is merely the statistical index on the consciousness plane of the activities of molecules of mind which perhaps constitute the subconscious. The thought has intriguing possibilities.

I do not claim that this is a good example of what I mean, or that this relationship is either true, or if true that it is universal. I have merely used it in an attempt to illustrate how an understanding of the exactly evaluable relationships of physical science and engineering may illuminate and clarify the understanding of human reactions even though the human forces and reactions cannot be evaluated in arithmetical terms.

The example just cited relates to an individual human reaction. In the field of mass human be-

havior, such as may be studied through the use of human statistics, much more consistent and universal relationships may be discovered. In many cases, in fact, such relationships may be evaluated and quite accurate predictions made therefrom. The life insurance business is founded on human statistics and many other businesses make use of similar records of average or mass human behavior. The method is analogous to certain aspects of thermodynamics, for instance, where temperatures and pressures of gases appear as statistical averages or summations of individual molecular velocities and impacts. The magnitudes relating to the individual molecules (or persons) cannot be measured and would probably be of little significance if they could, but the statistical summations or averages are significant and are found to obey certain laws or relationships by means of which correct conclusions can be drawn and useful predictions made. Thus the scientific method may be applied even to human behavior, and relationships found analogous in many ways to those governing the behavior of inanimate things.

The point I am trying to make is this, that if natural laws are universal in their operation though they can be exactly evaluated only in their physical manifestations, a knowledge of these physical relationships such as must result from an engineering education cannot but be of immeasurable value in interpreting observations of either material or human reactions in whatever walk of life one may be placed.

Up to this time I have not attempted to define exactly what I mean by an engineering education. Perhaps this hesitation has been due to my realization that there are those present much more capable of doing this than I. However, it seems my thesis can hardly be complete without such a definition, so I shall now attempt it.

A Definition of Engineering Education

Such an education, as I see it, will comprise a content and a method, of which the latter is the more important. As to the content, it would start of course with the study of the characteristics of pure abstract numbers, that is, arithmetic, the algebra, and the calculus. It would then advance to the study of the characteristics of Euclidean space, namely, geometry. It would then proceed logically to the study of the matter which occupies space and its behavior on the mass plane, namely, the physics and mechanics, thus introducing the concepts involving time and energy. The next logical step would seem to be the study of the behavior of matter and energy on the molecular plane, namely, thermics and thermodynamics. This might logically be followed by the study of the behavior of matter and energy on the atomic plane, that is, chemistry and electrochemistry and, finally, with a study of the behavior of matter—energy on the electronic plane, namely, electricity and magnetism, and of energy on the vibratory plane, namely, optics and radiation.

Perhaps these technical phases of a purely *engineering* education should stop here, but if time permits, at least a glimpse should be taken of subatomic physics, relativity, and the wave mechanics, because although these subjects may not be understood and have little engineering significance, enough of their import can be gained to emphasize the oneness of the universe. For instance, the statement that in certain concepts of the wave mechanics an electron may be defined as "the one spot in the universe where a multiplicity of waves fail to completely neutralize each other" conveys a sense of identity between the electron and the universe in a manner challenging to thought. Along with these subjects there must of course be some language, some history, some economics, some finance, and some art.

Now as to methods, what is fundamental is the need to stress all through the educational process, the interrelationships between all these seemingly dissimilar subjects, the reappearance in them all of the fundamental laws, and the dual nature of many of the phenomena. Whenever, in any one of these subjects, a fundamental law lifts up its head it ought to be tagged. Of course, my memory may be at fault and much has been learned in 30 years, but I cannot recall that when I was at Worcester any one ever told me, when I was studying algebra, that I was learning the mysteries of pure numbers, the foundation of all exact knowledge; or when I was studying geometry that I was investigating the properties of pure Euclidean space; or suggested to me that physical space could possibly be other than Euclidean; nor when I was studying thermodynamics do I recall that any one took the trouble to point out that the temperature and pressure values with which we dealt were merely the statistical indications on the mass plane in which we worked, of purely mechanical phenomena which were taking place on the molecular plane; that temperature, for instance, was merely a mass plane indication of average molecular velocity, and pressure a mere statistical summing up of molecular impacts. Of course, in those days the electron had hardly been discovered, and atomic structure was still a largely unknown subject; so it is not surprising, of course, that I never learned in my study of chemistry, of the intriguing story of the ordered sequence of the elements, atomic numbers, isotopes, and all the rest of that beautiful and fascinating tale. An engineering education certainly ought to embrace all those things and many more of similar nature, and I have no doubt that such an education, as now taught, does embrace them. From the standpoint of true "education," that is, of leading the mind out from its prison of inherited and acquired prejudices and its slothful acceptance of standardized thought forms into the free and open universe where it can receive the stimulation of truth impinging, like cosmic rays, from every direction, the comprehension of the relationships between these various elements of knowledge is of far more importance than the mere acquisition of the knowledge itself. Something like this is my conception of a real engineering education.

A Tree With Roots of Education

Perhaps it will serve to sum up my argument if we think of one's life work as a tree, with roots of education furnishing support and sustenance, trunk and

branches of training serving to keep its head firmly attached to the solid ground of practicality, with leaves of experience and flowers and fruit of accomplishment overtopping the whole. A tree, if it is to be strong and sturdy, must have its roots in soil both firm and fertile. What soil could be more fertile to nourish the tree of one's life work than the world's accumulated knowledge of the laws of nature which govern the universe, and where can such a soil be found more sound and firm than the clearly defined and exactly evaluated expressions of such laws in the realm of physical science and engineering? It seems difficult to believe that any significant life work so rooted could be other than strong and sturdy and capable of healthy growth and abundant and useful productivity.

Having now reached the end of my thesis it will doubtless have become apparent to my audience, as it has to me, that the engineering education of which I have been thinking is not a specialized civil, or mechanical, or chemical, or electrical engineering education and training. It seems to correspond most closely to a course in general science, and quite naturally so, I think, because it is such a course that would seem to constitute the most practical engineering education for any other than an engineering life work. Such an education would naturally not include all the specialized training required for an engineering career. In the terms of my tree metaphor it would include the soil, the root structure, and possibly the trunk of the tree up to the point where the first branch appears. Beyond that point, special training for the intended career would seem to be required.

In conclusion, I submit that an engineering education such as I have attempted so inadequately to suggest, which opens the mind, shows it how nature itself does its work, and teaches it to apply that knowledge through original thinking to the specific problems of one's life work, is a preparation for that life work which has, and in the very nature of things can have, no equal.

Some Features of the Boulder Canyon Project

A brief résumé of some of the principal features of the Boulder Canyon project is presented herewith. Included in the paper are: (1) a brief review of historical facts leading up to the project; (2) an outline of principal features of the Boulder Dam—Los Angeles power transmission system, which includes a 270-mile 275-kv line; (3) a description of the distributing system in Los Angeles, which this line will feed; and (4) brief discussion of the flood control and water supply features of the project.

By
E. F. SCATTERGOOD
FELLOW A.I.E.E.

Bureau of Power and Light
Los Angeles, Calif.

MEN OF VISION serving the City of Los Angeles, Calif., in 1905–07, when the city had a population of 160,000, realized that the limited supply of water from local streams would not provide for a population in excess of possibly 350,000 people, and that for additional supply it would be necessary to go a distance of 250 miles for water from the Owens River watershed along the eastern slopes of the Sierra Nevada Mountains. The possibility of such a supply was studied, together with the possible power developments along the aqueduct resulting from bringing water from an elevation of 4,000 feet to that of the city near sea level, and careful studies were made respecting the project's justification from the standpoint of community benefits and self-liquidation. As a result, bonds were approved in 1907 for the construction of the aqueduct, and additional bonds were approved in 1910 for the construction of the first permanent power generating works along the aqueduct.

The first announcements of the proposed project to the people of Los Angeles, in July 1905, clearly set out that the possibility of developing large blocks of power at low cost would constitute the economic justification for a city of only 160,000 population to attempt constructing a project of such great magnitude. A $24,000,000 project was noteworthy in those days even for large centers of population. The blocks of cheap power have been developed by the city through its Bureau of Power and Light and have been utilized, as visualized and recommended by the management of the Power Bureau more than 20 years ago, for the purpose of establishing industries and of making electricity a convenience in domestic and commercial life, available to all.

During the first 10 years following the beginning of operations by the municipal system in Los Angeles in the fall of 1916, the encouragement of industry by the bureau and through the lowering rates of the Southern California Edison Company, Ltd., adja-

A paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. summer convention, Ithaca, N. Y., June 24–28, 1935. Manuscript received Feb. 21, 1935; released for publication March 1, 1935.

cent to the city, resulted in increasing gross output for the metropolitan area from $167,000,000 for the first year to $1,250,000,000 for the eleventh year; the total invested wealth of the community three-fold; the business of the private electric companies of the community fourfold; and the value of their stock an average of approximately ten points upward.

Of the 3 formerly-existing privately-owned distributing systems within the city, 2 were purchased and effort is being made to purchase the third. Through the establishment of low rates for electric service, but not unduly low, and through the purchase of existing distributing systems, results have been accomplished for the benefit of the community, without harm to invested capital, incomparably greater than could have been accomplished through paralleling or through undue lowering of rates which would have curtailed expansion at times for want of funds.

Los Angeles and southern California have become recognized as an important industrial community. It was manifestly a duty to the community on the part of the Los Angeles Bureau of Power and Light

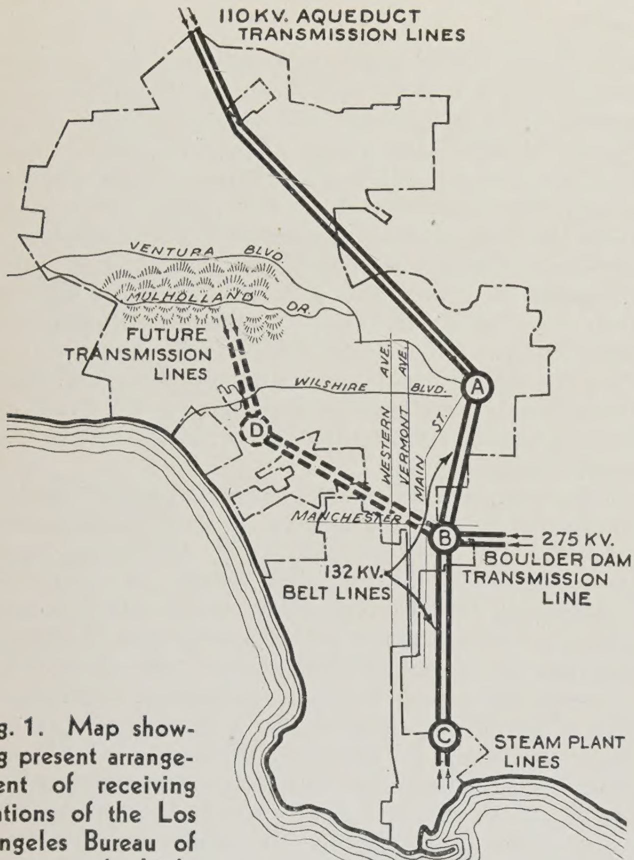

Fig. 1. Map showing present arrangement of receiving stations of the Los Angeles Bureau of Power and Light

to take the lead in bringing to the city additional large blocks of low cost power for the encouragement of additional industrial expansion and the maintenance of an approximation to an industrially and commercially balanced community. Exhaustive investigations showed that the largest block of power, and the lowest in cost, could be obtained, and community welfare otherwise served best, through the construction at Boulder (or Black) Canyon on the Colorado River of a high dam for the development of hydroelectric power, flood control, and storage of water for irrigation and domestic use—thus solving for many years to come the 2 most pressing problems, namely, a large permanent supply of low cost power and domestic water for future generations. On the strength of these investigations, the Bureau of Power and Light was instrumental, in coöperation with Arthur P. Davis, Director of the United States Bureau of Reclamation, in furthering national legislation authorizing the Boulder Canyon project and in furthering appropriations for its construction.

Careful and extensive surveys of the Southwest made in 1925 show the need for the waters that may be conserved by the Boulder Canyon project and for the block of low cost power that may be developed and transmitted to points of use. It is believed from such studies that the complete utilization of the power over a period of possibly 6 or 8 years and corresponding utilization of water for irrigation and domestic use as required will result in doubling the total invested wealth of the Southwest and in more than doubling the total gross annual output of all industry.

By providing flood protection, the project will enable farmers to secure necessary loans or to extend them in areas heretofore threatened by destructive floods, and thus greatly will benefit the metropolitan centers as well as the areas protected from flood and benefited by a more reliable water supply through seasonal and yearly stream regulation.

Boulder Canyon power will be delivered in Los Angeles at low cost and will assist in community development; its purchase was essential to the financing of the Boulder Canyon project and of great value to the Southwest. The Bureau of Power and Light, through the Department of Water and Power, has contracted with the United States government for a portion of the power privileges created through the construction of the project dam in the Black Canyon, and accordingly now is constructing a system for the transmission of power from the power plant below the dam to a central receiving station in the City of Los Angeles, for general distribution and use within the city.

Construction of the power transmission system, approximately 270 miles in length, is being financed through a loan of $22,800,000 by the Reconstruction Finance Corporation on the basis of repayment in full within 20 years, with interest. The loan will result in actual profit to the federal treasury because of the high interest rate charged. The transmission system will consist of 2 275 kv circuits, each divided into 3 equal parts by 2 switching stations along the way. The system will deliver, reliably, 240,000 kw at the receiving station in the city.

The Secretary of the Interior has required the Power Bureau, under the terms of the Boulder Canyon Project Act, to generate and transmit power allocated to and contracted for by the cities of Pasadena, Glendale, and Burbank, Calif., and those municipalities have contracted for the right of use of a portion, totaling 37,368 kw, of the 240,000 kw of

reliable operating transmission capacity on the basis of costs of installation, operation, maintenance, and replacement, with reasonable allowance for overhead percentages.

Research work conducted over a period of 5 years by the Bureau of Power and Light, in its laboratories; at the Harris J. Ryan high voltage laboratory at Stanford University; and on the part of leading manufacturers of electrical machinery, cables, and insulators in their laboratories, made possible the following developments: (1) copper conductors suitable for 275 kv, which did not exist previously; (2) clamps and other hardware suitable for supporting the particular conductor contracted for, which is 1.4 inches in diameter and consists of a hollow copper tube made up of 10 interlocking segments; (3) oil circuit breakers for 287 kv, and 2,500,000 kva interrupting duty, with necessary relays, which will clear any section of either transmission circuit that may be in trouble within approximately $^1/_{10}$ second from the instant of short circuit; and (4) main generating units in the plant with only 17.5 per cent inherent reactance. This and other pioneering work has made possible the provision of generating units, transmission lines, and receiving station equipment at a total cost of $30,000,000 while the investment cost using the best standard machinery, transmission equipment, and construction practice now in use would approximate $42,000,000 and would afford less flexibility and reliability.

The total estimated cost of the transmission line and receiving station facilities is $22,800,000. Of this amount, the transmission line, including right of way and communication facilities will cost $13,700,000; the intermediate switching stations including operators' cottages and permanent camp facilities $2,000,000; the autotransformer step-down station $1,000,000; the receiving station facilities including synchronous condensers $4,400,000; and the transmission line extension from receiving station *B* to receiving station *D* (see figure 1) $1,700,000.

Receiving Stations and Distributing System

Preliminary Studies. Engineers of the Bureau of Power and Light realized that the amount of power that could be supplied to a solidly interconnected system for distribution must be limited. The limitation might be controlled by ability to provide successful control equipment, but the actual limiting features are combined economy of investment, maintenance, and replacements coupled with reliable operating conditions.

In order that over-all economy and reliable service may be realized, the main power supply for Los Angeles, which comes from distant hydroelectric plants in large blocks, must be delivered in blocks thus limited in capacity at separate receiving stations in different sections of the city; and from the rceiving stations it must be distributed over moderately high voltage lines to numerous local distributing stations in each of the respective sections.

It is true, also, that in the interest of economy and reliability the required steam auxiliary and stand-by capacity must be generated at some advantageously located center and made available by means of interconnecting lines to each of such central receiving stations for auxiliary purposes and for stand-by in emergencies. The alternative of having separate steam auxiliary and stand-by for each block of hydroelectric power would be exceedingly costly in itself and, furthermore, there would be no provision for profiting by diversity through interchange between

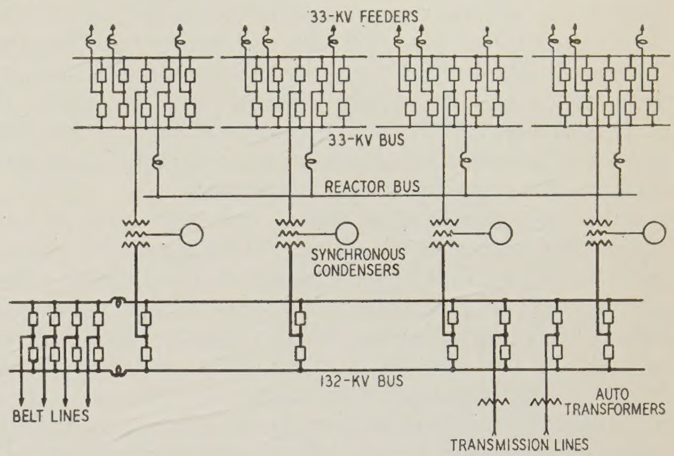

Fig. 2. One-line wiring diagram of a typical receiving station

such central receiving and distributing stations, nor for the greater reliability afforded by such interconnecting lines.

General Plan of Distributing System. Saturation of the area when fully developed in and immediately around Los Angeles probably will require a power supply of 1,500,000 kw. This area and load will be supplied ultimately from 5 or possibly 6 independent power systems, each with its central receiving and distributing stations located more or less centrally within one of the respective load sections of the city. Each system ultimately will have a load with a peak demand commensurate with 250,000 kw. At the present time 3 such receiving stations are in operation and are designated as stations *A*, *B*, and *C* (see figure 1).

A fourth central receiving station, to be known as station *D*, is projected and will be constructed in conjunction with the Boulder Canyon power transmission system, the main terminus of which will be at Station *B*, located in the east central part of the city, with station *A* at the north and station *C* in the harbor district to the south, as shown in figure 1. Figure 2 shows a one line diagram of a typical central receiving and distributing station. The transmission circuit voltage of 275 kv is transformed to the 132 kv bus voltage by means of autotransformers, which, technically speaking, are part of the transmission lines.

Power is distributed from each receiving station to the local distributing stations of the respective districts at 33 kv. The circuits are radial from the receiving station and generally tandem from one local station to another. The main 33 kv receiving station bus is sectionalized into 4 independent sections, each

bus section having its own 132–33 kv transformer bank. Each bus section also is connected to a reactor bus through rather large 33 kv reactors. Under normal operating conditions there are practically no energy losses in these reactors.

The various receiving stations are tied together by duplicate 132 kv belt circuits, the purpose of which is to hold the several systems in synchronism, to supply power to any one system from the other systems in event of transmission circuit failure, to make the steam reserve plant available to all the systems, and to equalize the difference between the power available and the power demands of the various systems. The belt circuits are designed to transmit the full load of any one system of 250,000 kw, which would be necessary in event of a complete failure of its regular source of supply.

At each receiving station, the belt circuits are connected through oil circuit breakers to an extension of the main 132 kv duplicate station bus. Between each of the duplicate busses so extended and the corresponding main station busses are large reactors. Each reactor has a current capacity equal to $^1/_2$ of the total station capacity.

Station *A* was put in service 18 years ago. In this station, the arrangement of busses is slightly different from that described and the high voltage bus is operated at 110 kv, the transmission voltage from the aqueduct plants, instead of 132 kv. The tie between station *A* and the belt circuits is the same as described except that transformers incorporating the necessary reactance are installed between the 110 kv station bus and the 132 kv belt circuits.

Each local distribution station supplies an area of from 3 to 7 square miles depending upon load density. Three sizes of stations are standard, 3,000, 10,000, and 50,000 kw. These stations are all of the indoor type and a great deal of attention is given to the architectural details of the stations and to the appropriate landscaping of the grounds. Figure 3 shows a one line diagram of a typical local distribution station.

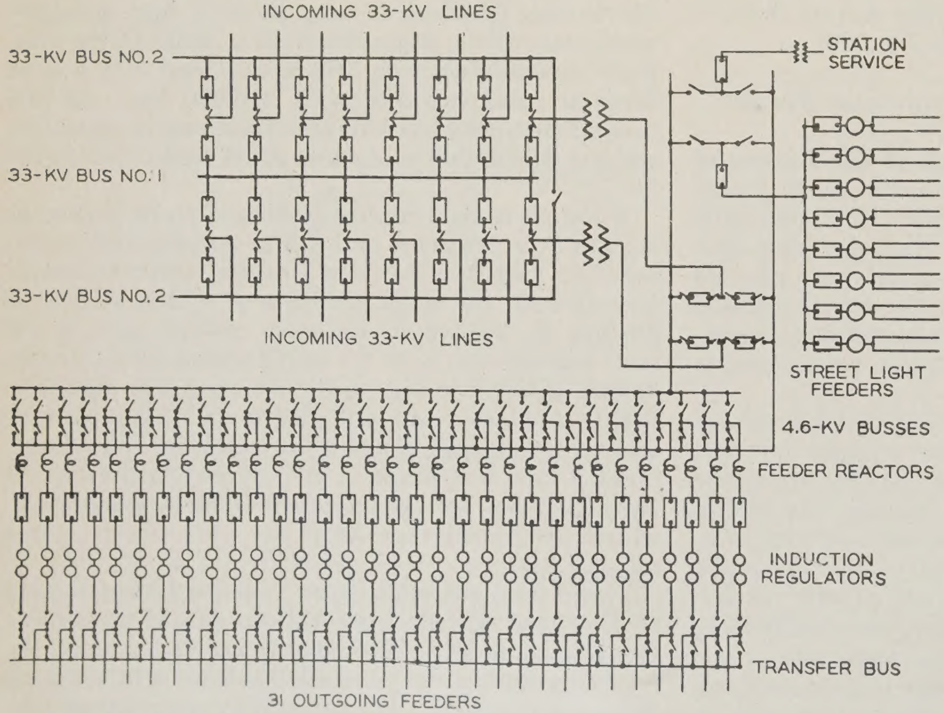

Fig. 3. One-line wiring diagram of a typical distributing station

Large industrial consumers having loads of 1,000 kva or greater are generally supplied directly from the 33 kv system. Each consumer has connections to 2 independent 33 kv circuits. These circuits are entirely separate from the 33 kv circuits supplying the local distribution stations.

When developed to a peak load of $1^1/_2$ million kw, the system as described will have a short-circuit duty in its various parts as follows: The 132 kv belt circuits, being the common tie between the various systems, will have a short-circuit duty not to exceed 3,500,000 kva. The duty at any receiving station will not be more than 2,500,000 kva on the 132 kv bus, and 1,500,000 kva on the 33 kv bus. The duty on any 33 kv distribution station bus will not be more than 1,000,000 kva.

Boulder Canyon Project

The Colorado River Boulder Canyon storage and power project, which now is nearing completion, will provide needed flood protection in the Imperial Valley and other agricultural areas in California and Arizona along the lower reaches of the river; will regulate the flow and conserve the flood waters for the benefit of irrigation and domestic supply; and will provide large blocks of low cost electric power.

The flow of the Colorado River varies greatly through seasons of the year and through periods of low and high annual precipitation in the river basin and run-off. The average flow through Boulder Canyon site under present conditions of water use in the upper basin states equals 22,000 cubic feet per second, which corresponds to an average yearly run-off measured at the Boulder Canyon site of 15,915,000 acre-feet.

During the months of May, June, and July the annual flood run-off takes place, and during early fall the river flow reaches its low mark for the year. At this period the flow is often less than the amount of water required for irrigation below in California and Arizona. During the year 1934 the low flow was but 1,570 cubic feet per second, while the usual total requirement for irrigation during the early fall months is approximately 5,000 cubic feet per second. This shows the great necessity for conservation of flood waters and regula-

tion of the stream for the benefit of agriculture and in order to make possible the needed additions to the domestic supply of cities of southern California.

Great benefit will result from the storage project through the elimination of silt amounting to a yearly average of something in excess of 100,000 acre-feet now passing the Boulder Canyon site. The great reservoir will provide ample capacity for intercepting the burden of silt for centuries to come. The storage capacity is equivalent to the silt of 300 years, but future storage at Glenn Canyon will intercept more than half the silt and reservoirs above Glenn Canyon, which will be provided for power development, will help regulate the flow and reduce the capacity requirement at the Boulder Canyon storage for flood protection and conservation purposes.

Imperial Valley lies from 100 to 300 feet below the level of the river as it passes southward between its dykes to the east, and the valley is nearly that distance below sea-level. The danger of floods has been a continual menace to this great valley. Millions of dollars have been spent for construction and maintenance of levees thus seeking to protect the region from overflow, with only partial success. Several breaks of magnitude in the levees occurred during 1905–06 and 1907, causing inundation of much of this rich valley floor and untold damage to crops and homes. To complicate the situation further, the reaches of the river where breaks in the levees generally occur are in Mexico and are thus under foreign jurisdiction.

Through the sale of the leases of power privileges the United States government will receive, in addition to full reimbursement for its investment with interest within 50 years and in addition to funds for yearly payments to the states of Arizona and Nevada in lieu of taxes, estimated surpluses or profits amounting to $63,000,000 for the period, together with further profits over the period amounting to the difference between 4 per cent interest on an average of $60,000,000 and the percentage of interest actually paid by the government.

The solid concrete dam rises 587 feet above the natural water level of the river creating a storage capacity of 30,500,000 acre-feet or more than 4 times the capacity of Gatun Lake along the Panama Canal. When filled, the reservoir will extend 115 miles up the canyons of the Colorado between the states of Arizona and Nevada and 35 miles up the valley of the Virgin River to the north in Nevada.

The ultimate installed capacity of the power plant will be approximately 1,400,000 horsepower at minimum operating head, and will consist of an equivalent of 16 main generating units of 65,000 kw rated capacity each, with a maximum capacity of 82,500 kw each. The machinery and equipment at the power plant will be installed by the federal government and paid for by the allottees of power as advanced rentals in full with interest within 10 years. Title to the complete project, including machinery, will rest permanently with the United States government.

The project will be operated under the direction of the Secretary of the Interior: first, from the standpoint of flood control; second, from the standpoint of water conservation and use for agriculture and domestic purposes; and, third, for the benefit of power. It is declared that the firm or reliable power will equal 4,330,000,000 kilowatt hours at the plant for the first year of operation and will decrease by the amount of 8,760,000 kilowatt hours each year on account of the increased use of water in the upper basin states. In addition to firm power there will be for many years in excess of 200,000 horse power of secondary power available on an average of 70 per cent of the time.

The Bureau of Power and Light of Los Angeles has been designated the generating agent for itself and all public allottees and the Southern California Edison Company, Ltd., as agent for itself and other privately owned power companies. The Metropolitan Water District of Southern California, which was formed for the construction of an aqueduct from the Colorado River for delivering domestic water to 13 cities of southern California, including the City of Los Angeles, was allotted 36 per cent of the firm power and the first right of secondary power for pumping water in and through the aqueduct in order to lift it over the divide; the Bureau of Power and Light of Los Angeles and 3 other municipalities were allotted 19 per cent; the private power companies 9 per cent; and the states of Arizona and Nevada each have an option, which they may use any time during the 50 year period in part or in whole, on 18 per cent of the firm power. The power allotments enumerated are made under firm contracts requiring the allottees to pay for the right of use of the falling water whether utilized or not; and each of the 2 principal lessees or generating agents are obligated to pay for half of the power not used by the states of Arizona and Nevada under their options.

Payments to the federal government for the right of power privilege, that is, the right to use the falling water below the dam for the generation of power, are based upon 1.63 mills per kilowatthour for firm power and 0.5 mill for secondary power, a rate that may be changed at the end of 15 years and every 10 years thereafter, and that is intended to be based upon the cost of power otherwise available in competitive centers.

Justification for the development of a great water and power project like the Boulder Canyon project on the Colorado River depends upon 2 principal factors: (1) the engineering feasibility and the reasonableness of cost of the project itself in proportion to the amount of resources made available; and (2) the sufficiency and permanency of demand for such resources and the actual need for them in the upbuilding of the community affected. These resources may consist of conserved water, developed power, or increased wealth resulting from flood protection or navigation.

The Boulder Canyon project is wholly self-liquidating, including the cost of protection against disaster from floods to large agricultural areas below it, and will result in the creation of resources that will make possible opportunity for livelihood and happiness of an increasing multitude of people in the Southwest.

Circuit Breakers for Boulder Dam Line

Because of its length, 270 miles, the 275 kv transmission line from Boulder Dam to Los Angeles, Calif., requires extremely high speed switching for stability. To meet the requirements, a high voltage impulse circuit breaker, extending the oil blast theory to cover a multibreak construction with double cross-blast ports, has been built. It provides over-all switching times consistently less than 3 cycles (3/60 second). Approximately 10 per cent as much oil is used as in a comparable breaker of conventional design, and only 1/10 of this is exposed to arcing. Large factors of safety are provided over and above the interrupting rating of 5,000 amperes, 287 kv, or 2,500,000 kva.

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THE 275 kv transmission line under construction from Boulder Dam to the City of Los Angeles, Calif., a distance of 270 miles, is the highest voltage transmission line yet undertaken, and the longest line without branch circuits. Because of the distance covered and the amount of power to be transmitted, the line may be required to operate near the stability limit. To secure the maximum through power under fault conditions, the 2 parallel tower lines are united and sectionalized at 2 desert switching stations located respectively 90 miles from each end of the line. At each switching station and at sending and receiving stations 4 2,500,000 kva circuit breakers are to be installed, so connected that in the event of a fault anywhere on the line, only one 90 mile circuit need be cut out. Power then will be transmitted over the remaining 90 mile single circuit and 180 miles of 2 circuit line.

Even with this amount of sectionalizing, stability studies have indicated that a reduction of switching time from 8 cycles to 3 cycles may be expected to produce a substantial increase in the maximum power limit. In an extreme case, this increase might approach 50 per cent. Three cycle operating time, therefore, has been specified for the high voltage circuit breakers to be installed both at terminal and intermediate switching stations.

Full text of a paper recommended for publication by the A.I.E.E. committee on protective devices, and scheduled for discussion at the A.I.E.E. summer convention, Ithaca, N. Y., June 24–28, 1935. Manuscript submitted Jan. 9, 1935; released for publication Feb. 4, 1935.

Circuit breakers designed along conventional lines for this high voltage would be enormous and would require a tremendous volume of oil, very heavy foundations, and special oil handling equipment; such breakers thus would be particularly inconvenient for a desert location. Considerable time would be required to drain such a circuit breaker, even for inspection. In fact, all the operations of service and maintenance would be complicated, especially at the remote points where some of these circuit breakers are to be installed. The requirements, therefore, appeared to indicate the desirability of a new type of breaker; the breaker developed to meet these requirements is described in this paper.

The principal novel features of this circuit breaker are: its high speed operation, 3 cycles from initiation of tripping impulse to interruption of circuit; and its small oil volume, about $^1/_{10}$ that of an equivalent breaker of conventional design. Furthermore, the design of the breaker is such that the oil exposed to arcing is only about 1 per cent of that exposed in an equivalent conventional breaker. Its high speed operation results in:

1. Improved system stability.
2. Reduced damage to line conductors and insulators from dynamic current following faults.
3. Reduced maintenance. One cycle or less of arcing produces negligible burning on contacts. Oil deterioration is very slight.
4. Improved service. A voltage dip is hardly noticeable even with sequential operation.

Advantages of the small oil volume are:

1. No special oil handling equipment required.
2. Negligible fire hazard.
3. Unusually short time to drain and refill.
4. Interior parts available for inspection in short time.
5. Large saving both in first cost and replacement of oil.
6. Low weight simplifies foundation problem and difficulties of transportation and erection. All parts are light in weight, giving easy handling.

Theory

The oil blast theory was enunciated in 1931 and has been described and amplified in various publications since that time (see references at end of paper). In brief it has been shown that the behavior of an oil blast circuit breaker is explained by the equation:

$$\frac{\frac{v}{t}}{\frac{v}{d}} = \frac{d}{t} \tag{1}$$

where

v = voltage
t = time
d = distance
v/t = rate of rise of recovery voltage
v/d = oil dielectric strength
d/t = oil velocity

If the oil velocity is greater than d/t, the arc can-

not restrike after a current zero; if less, it may restrike. In this equation, the dielectric strength of the oil has been shown by experience to be approximately 55 kv for 0.1 inch, a value not sensitive to oil condition. The reasonableness of this value has been demonstrated by impulse tests on new and on used oil.[1]

Where pressure and not velocity is measured, the 2 are related by equation 2, which expresses the well-known law of flow of hydraulics:

$$v = \sqrt{2gh} = 12.8\sqrt{p} \tag{2}$$

v = velocity in feet per second
g = gravitational acceleration, 32.2 feet per second per second
h = head in feet
p = pressure in pounds per square inch
The constant is for oil of density 0.9.

For the original form of contacts, a single wall of oil formed at substantially the velocity of linear oil flow as shown in figure 2*a*. Later the cross blast arrangement was developed for higher voltages as shown in figure 2*b*. In this form the gas bubble is separated from both contacts by oil walls which must be punctured to reëstablish the arc. In the most recent development 2 ports are provided, as shown in figure 2*c*. The gas bubble is divided into 2 parts, giving a total of 4 oil walls forming at the linear velocity of oil through the ports.

1. For all numbered references see list at end of paper.

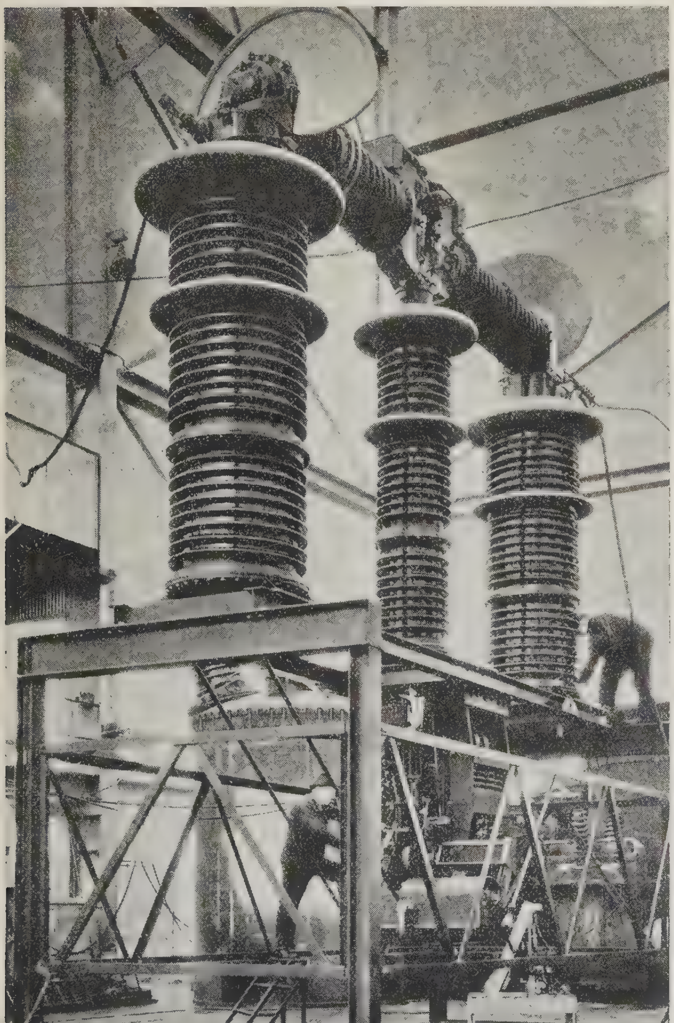


Fig. 1. One of the 287-kv single-phase high-speed impulse oil circuit breakers set up for test

The form of oil blast circuit breaker most suitable to meet the present requirements is the impulse breaker, in which a positive and definite oil flow is produced by a spring driven piston.[2] This form of circuit breaker has 2 important advantages: Since the oil is driven mechanically, it is not necessary to wait for the formation of an arc before oil flow is available to interrupt the circuit. This is important in securing high speed operation. Since the full oil velocities are available at light currents as well as heavy, it is not necessary to provide a long stroke. This makes possible the design of a circuit breaker of moderate proportions for this extreme voltage. The impulse theory has the further advantage that as a quantitative theory, it permits the quantitative design of this very high capacity breaker. Otherwise, the design would be dependent entirely upon the trial and error method, which becomes rapidly more cumbersome and expensive as the size of the apparatus increases.

Previously published studies have indicated the desirability of multiple breaks for high voltage, provided a structure is available that gives reasonably uniform distribution of potential between the various breaks.[3]

An oil flow should be maintained for a conservative length of time, say 4 or 5 cycles. The amount of oil required to keep up this flow is directly proportional to the velocity, and the pressure is proportional to the square of the velocity. The work done per operation is the product of these 2 and, therefore, is proportional to the cube of velocity, as shown in equation 3.

$$p = Kv^2$$
$$d = kv$$

$$e = pd = Kkv^3 \tag{3}$$

p = pressure
v = velocity
d = displacement
e = energy
n = number of breaks
K = constant
k = constant

By using several breaks, provided the recovery voltage is divided equally among them, the oil volume required to pass through several breaks is proportional to their number, but the required oil velocity is inversely proportional to the number of breaks. Therefore, the energy is inversely proportional to the square of the number of breaks, as shown in equation 4.

For n breaks providing the same aggregate velocity:

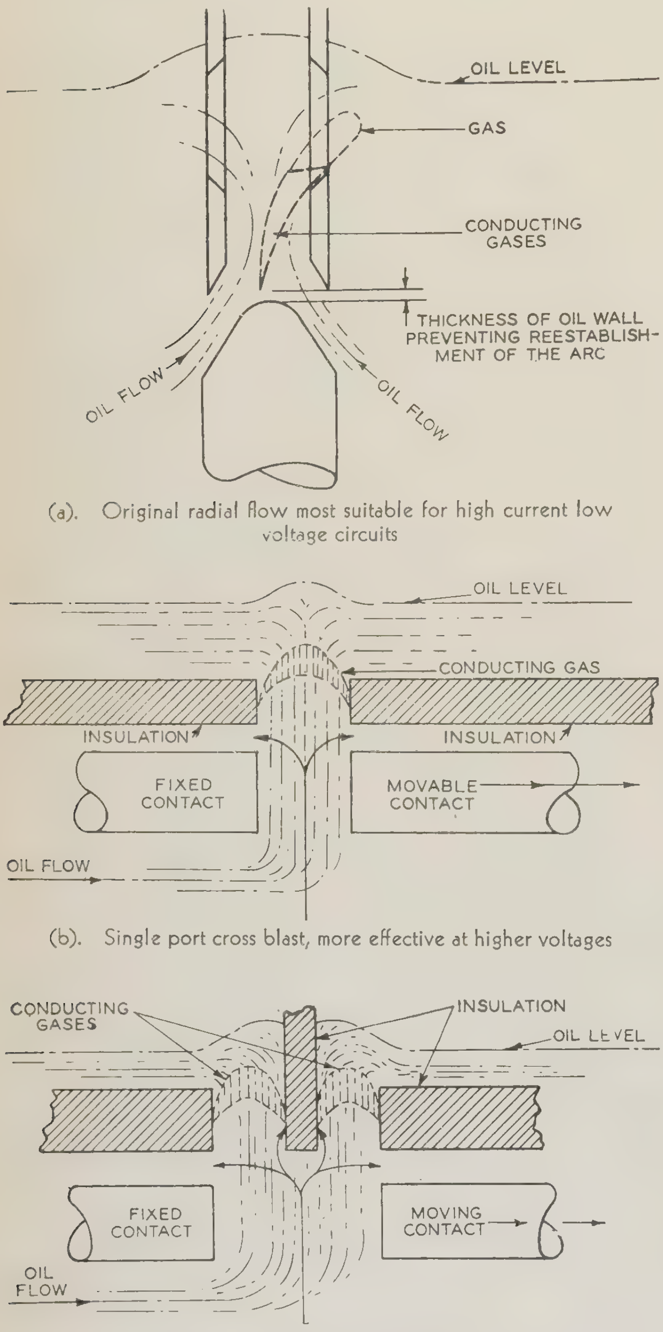
$$p = K\left(\frac{v}{n}\right)^2 \qquad d = kn\left(\frac{v}{n}\right)$$

$$e = Kk\frac{v^3}{n^2} \tag{4}$$

This relationship holds only so long as the division of recovery voltage among the breaks is equal.

Where the division of recovery voltage is unequal, the voltage appearing across the most highly stressed break would appear a logical choice instead of the total voltage divided by the number of breaks. On a line-to-ground fault on a multibreak tank type breaker, as much as 90 per cent of the total voltage may appear across the break on the ungrounded side.[4] A good deal of careful design work is necessary, therefore, if the relationship expressed in equation 4 is to be utilized to advantage.

As a preliminary to building the first 287 kv circuit breaker, a 138 kv breaker was constructed.



(a). Original radial flow most suitable for high current low voltage circuits

(b). Single port cross blast, more effective at higher voltages

(c). Double port cross blast most effective for high voltages. Further multiplication extends time required to uncover ports

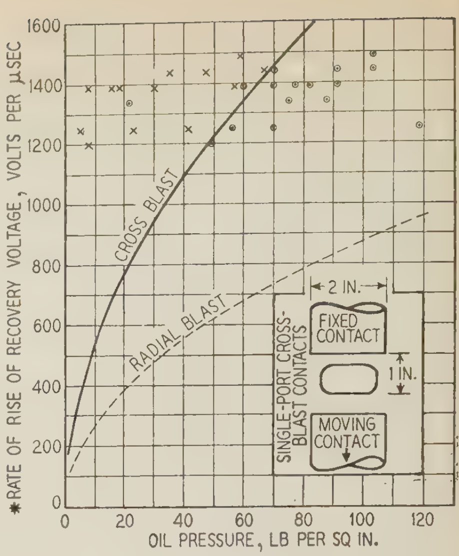
Fig. 2. Cross sections of contacts for 3 types of oil blast circuit breakers

Fig. 3. Experimental verification of relation between oil pressure and rate of rise of recovery voltage for one of 4 single-port cross-blast breaks

* Plotted recovery rate is calculated recovery rate times 0.48 where entire breaker was used, and times 0.63 where grounded half of breaker was short-circuited

× Pressure at next to last current zero

⊙ Pressure at last current zero



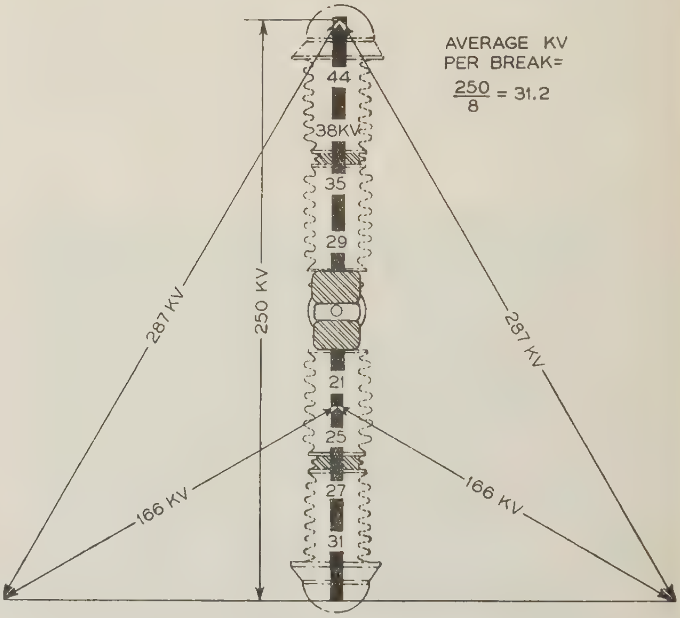


Fig. 4. Potential distribution across breaks of 8-break 287-kv impulse circuit breaker under worst field conditions

This circuit breaker had 4 breaks,[5] the individual breaks being as shown in figure 2*b*. Potential distribution measurements were made on this breaker to determine what fraction of the total voltage would appear across the most highly stressed break; figure 3 gives an analysis of these tests. In determining the rate of rise of recovery voltage which is used as the ordinate, the total rate of rise appearing across the circuit breaker was divided in accordance with the measured potential distribution, and only the value that appears across the most highly stressed break was used. The plotted test points, indicated by circles, represent the pressure and rate of rise at the last current zero, that is, at the time the circuit was interrupted. The crosses indicate the oil pressure and rate of rise at the previous current zero, eliminating only those tests for which at the previous current zero the contacts were too close together to uncover the oil port. The broken line

Table I—Test Data on 287-Kv 600-Ampere Single-Phase Impulse Oil Circuit Breaker, 60 Cycles

Test Volts, Kv	Initial Current in Arc, Amp (Effective)	Rate of Rise of Recovery Voltage, Volts per μSec	Cycles From Auxiliary Relay Trip to Interruption	Contact Separation, In. At Interruption	Contact Separation, In. At Previous Current Zero	Test No.
Full Breaker—8 Breaks						
	6,100	1,070	2.30	0.4	0	34
22	6,700	1,000	2.45	1.1	0.2	35
	7,700	1,130	2.60	1.0	0.1	36
	9,300	990	2.80	1.3	0.2	37
	4,100	2,000	2.75	1.3	0.2	18
	4,400	1,870	2.30	0.5	0	19
44	4,000	2,200	2.55	0.9	0	20
	6,800	1,560	2.40	0.8	0	21
	2,500	2,400	2.65	1.2	0.3	30
66	2,600	2,500	2.60	1.2	0.2	31
	3,100	2,200	2.45	1.0	0	32
	2,900	2,300	2.50	1.0	0	33
	3,100	2,500	2.35	0.8	0	26
88	2,000	2,900	2.35	0.9	0	27
	2,300	2,600	2.40	0.8	0	28
	2,100	2,800	2.60	1.2	0	29
	720	4,300	2.45	1.4	0.2	85
	760	4,700	2.45	1.2	0	86
264	760	4,500	2.55	1.5	0.3	87
	760	4,900	2.45	1.3	0.2	88
Half of Breaker—4 Breaks						
88	2,500	2,100	2.65	1.5	0.8	89
	2,500	2,300	2.85	1.8	0.8	90
	1,350	2,900	2.45	1.0	0	7
132	1,460	2,800	2.45	1.0	0	8
	107	660	2.45	0.7	0	16
	67	410	2.25	0.4	0	17
154	1,230	4,400	2.55	1.3	0.3	91
	1,350	4,200	2.65	1.4	0.8	92
176	1,140	4,500	2.70	1.5	0.9	93
	1,070	4,800	2.60	1.5	0.5	94
	990	4,300	2.85	1.9	0.9	95
220	970	4,400	2.50	1.1	0.3	96
	830	4,400	2.50	1.4	0.4	97
264	730	4,900	2.45	1.2	0.1	98
One Single Break						
33	1,690	1,190	2.75	1.9	0.2	99
66	3,800	2,100	2.40	1.2	0	100
	3,200	2,300	2.80	2.3	0.6	101
88	2,300	2,500	2.65	2.1	0.4	102
	2,400	2,400	2.60	1.6	0.1	103
110	1,850	2,400	2.45	1.2	0	104
	2,300	2,100	4.15	5.2	4.5	105

marked "radial blast" corresponds to an impulse dielectric strength of 55 kv for $^1/_{10}$ inch of oil, determined in the first work on the impulse breaker, figure 2*a*. This data merely has been replotted in terms of oil pressure instead of velocity. The full line of figure 3 has twice the ordinate of the broken line, to take account of the fact that the flow of oil is across the contact instead of radially, as in figure 2*b*. The fact that this line separates the region of all circles from that of mixed circles and crosses proves not only that the cross blast is, as expected, exactly twice as effective as the radial blast in terms of recovery voltage cleared for a given oil pressure, but also that the behavior of a multibreak breaker of this type can be predicted by determining the rate of rise appearing across the most highly stressed break and then applying the single break formula for the rate of rise so found.

Figure 4 shows the potential distribution determined for the 287 kv circuit breaker. The sides of the triangle represent the line voltage vectors. When the first phase clears, in the event of a 3 phase fault, the recovery voltage appearing across the phase is 0.866 times the full line voltage, and this is distributed across the 8 breaks of this circuit breaker, as shown in the diagram. Using this method of determining the recovery voltage rate across the most highly stressed break, figure 5 has been prepared. The lowest broken line is repeated from figure 3. Since this cross blast proved twice as effective as the radial blast, it seemed possible to break up the arc space further and secure even more effective use of the oil blast by the construction shown in figure 2*c*. Accordingly, in the new design 2 ports are employed instead of one for each pair of contacts. In the lower right-hand corner of figure 5 is shown a plan view of the arrangement. Oil carries the gas bubble into these 2 ports where it is broken up twice as much as with the single port arrangement of figure 2*b* and 3. On the assumption that the effectiveness in terms of recovery voltage should be twice as great in this arrangement as in that of figure 2*b*, the full line of figure 5 has double the ordinates of the full line of figure 3. So far, the data taken have not yielded any crosses, that is, there have been no "next to the last" current zeros at which the 2 ports have been uncovered. In all tests the circuit has been interrupted at the first current zero after the moving contact has uncovered the 2 ports, although in many of the tests the recovery rate was considerably higher than would have been cared for by the single port arrangement in figure 3. Additional tests are to be made to determine the limitation of this new arrangement and establish quantitative factors. The tests made so far, however, have established a considerable advantage in the double port for a high voltage circuit breaker.

Construction

Figure 1 shows one pole of the circuit breaker developed to meet the severe requirements of the

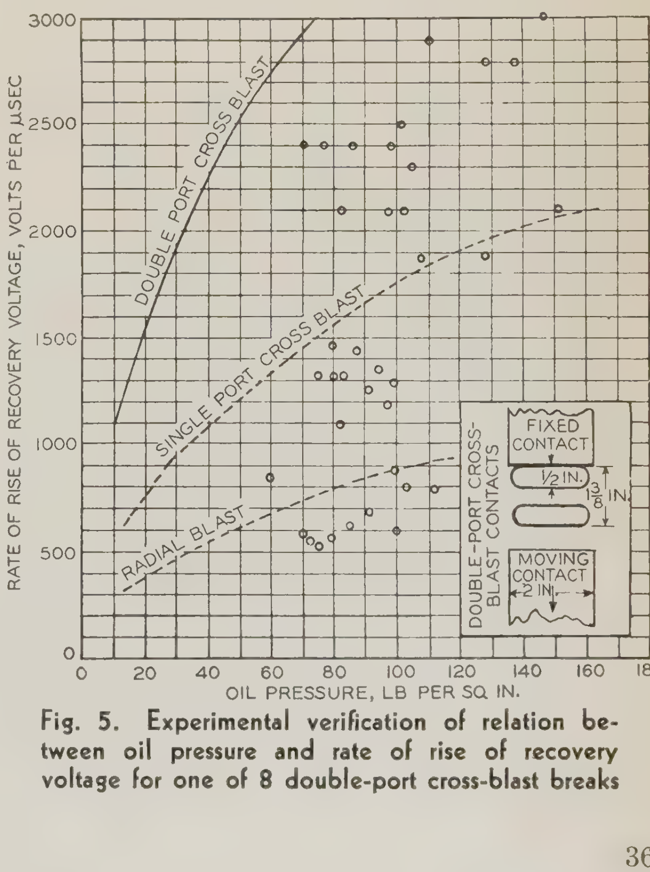


Fig. 5. Experimental verification of relation between oil pressure and rate of rise of recovery voltage for one of 8 double-port cross-blast breaks

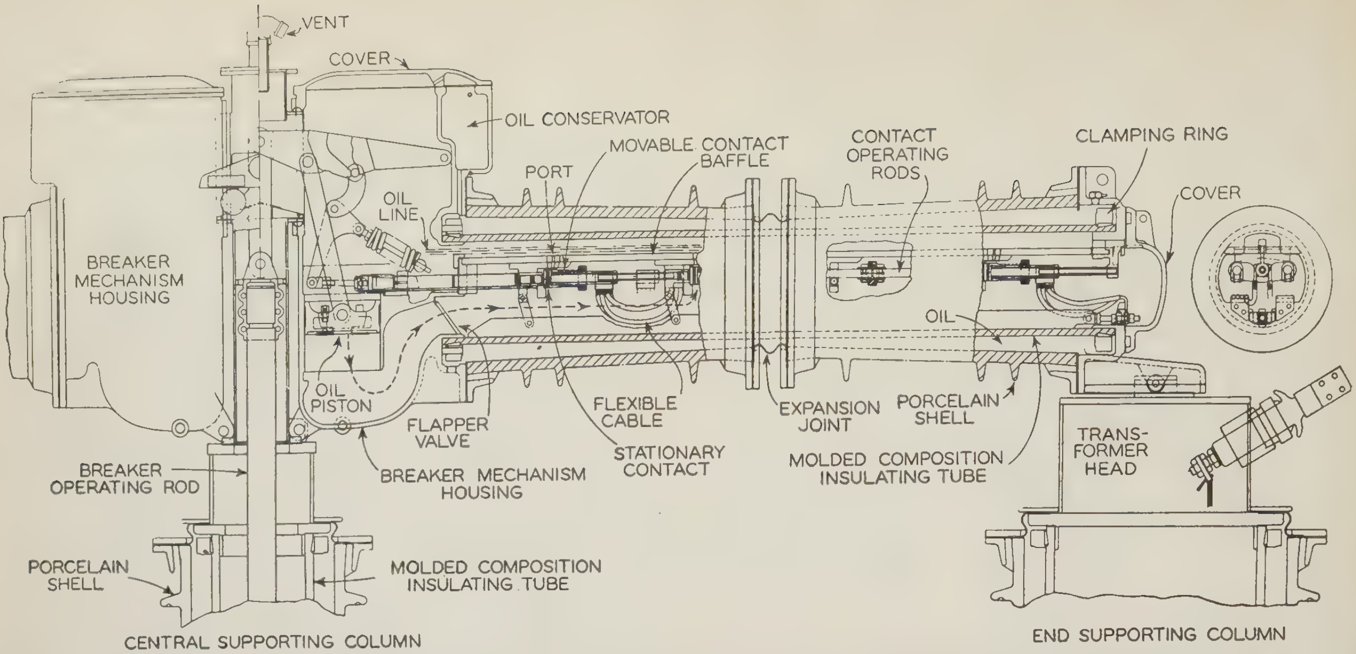


Fig. 6. Cross section of one element of the Boulder Dam–Los Angeles line circuit breakers; each single phase breaker consists of 2 elements

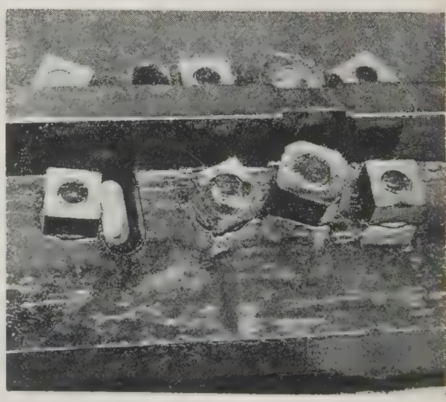
Boulder Dam–Los Angeles line, incorporating the structure indicated by the preceding theory. Instead of the single interrupting element of the 138 kv design, 2 have been provided, each containing 4 breaks and a piston to furnish the oil blast. These 2 interrupted elements are mounted through hinged joints upon a central column made up of a tube of molded insulating material protected from the weather by a porcelain shell. Through this tube the wood operating rod passes to the spring charged mechanism below. The outer ends of the interrupting elements are supported on cascade type current transformer columns by a roller joint to permit freedom of expansion and relative movement resulting from vibration, misalignment, or other causes. The pole is mounted upon a steel framework so as to provide adequate clearance from live parts to ground. A complete 3 phase unit of this design weighs approximately 110,000 pounds, as compared with 290,000 pounds for a breaker of conventional tank type design. It contains a total of 2,500 gallons of oil, compared with 23,000 gallons for the conventional design, or approximately $^1/_{10}$ as much total oil. The oil actually exposed to arcing is only 210 gallons, or somewhat less than one per cent of the oil exposed in the conventional breaker.

The construction of one of the interrupting elements is shown in figure 6. The interrupting element is built upon a tube of molded insulating material, which is protected from the weather by porcelain shells. These shells, however, are not subjected to any of the mechanical forces. The casting containing the piston and contact mechanism is bolted to one end of the molded tube. The other end is closed by a suitable casting. To disassemble the element, the 35 gallons of oil in one unit are drained off; the circular plate at the end of the unit then is unbolted, permitting the withdrawal of the diaphragm with all of the contact parts attached to it.

Detailed construction of this unit is shown in figures 7 and 8. Figure 7 shows the top of the diaphragm with the rib that braces it to the center of the top of the molded insulating tube. It also shows the exit ports through which the oil flows during operation. The central fin separates these ports so as to prevent the gas bubbles from coalescing after they have been driven through the ports. Figure 8 shows the lower side of the interrupting assembly. The 4 moving contacts are carried on crossheads which bridge the parallel wood rods. The circuit is completed to the moving contacts by means of heavy flexible cable, and each contact is provided with its separate spring to insure uniform pressure on all contacts. The contact surfaces themselves are made of a silver-tungsten alloy. The particular contacts shown have been through 30 or 40 short-circuit operations and show practically no burning. All of the spaces between molded insulating tube and porcelain shell are filled with oil, each space having its separate expansion chamber or conservator.

Each pole is operated by a spring charged mechanism providing positive high speed operation with

Fig. 7. Top of baffle showing discharge of double ports separated by longitudinal fin to prevent breakdown between hot gas bubbles



A—Motion of wood operating rod and piston: each step represents $1/2$ inch of travel of rod; $3/8$ inch of piston
B—Short circuit current
C—Piston pressure: (1) at interruption, 80 pounds per square inch; (2) maximum, 135 pounds
D—Current in opening trip coil

A—Arc voltage
B—Short circuit current
C—Motion of contacts: each step represents $1/6$ inch of travel; (1) contacts separate
D—Current in high speed opening relay coil

A—Total control current
B—Short circuit current
C—Pressure at end of tube: (1) at interruption, 110 pounds per square inch; (2) maximum, 143 pounds

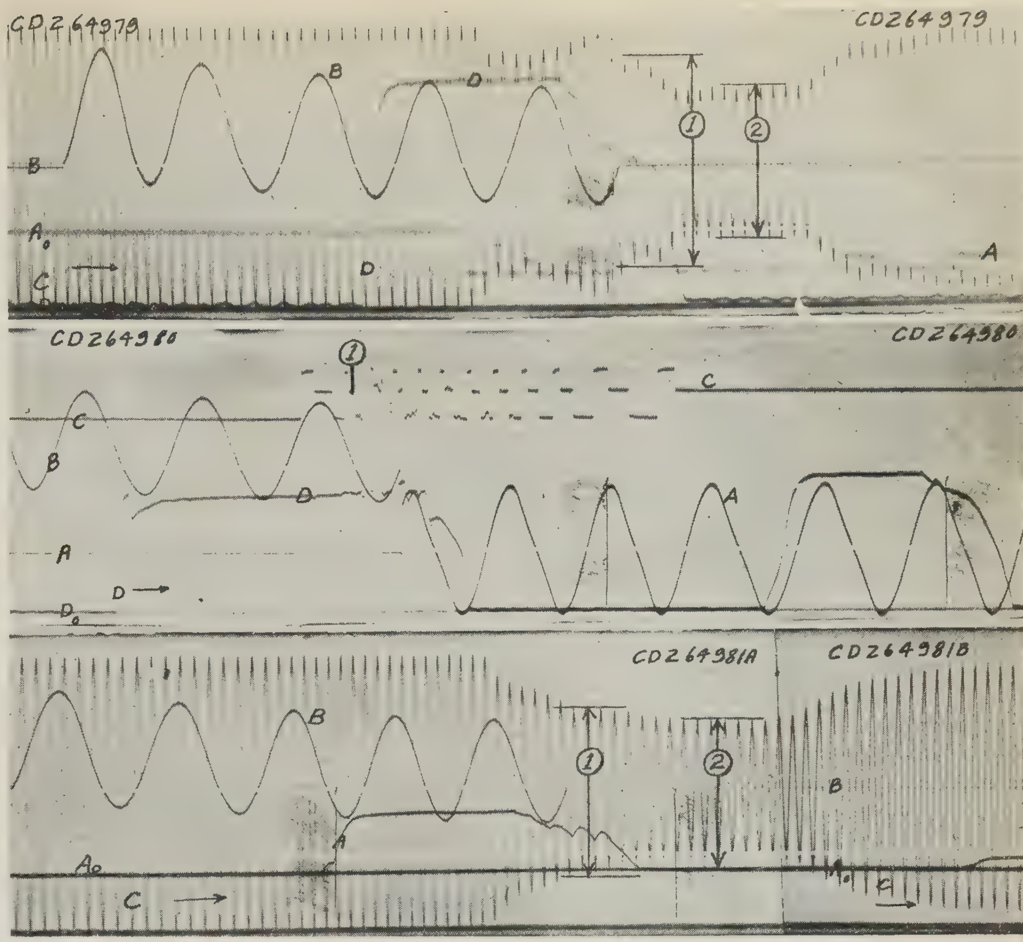


Fig. 9. Oscillograms showing $1/2$ of 287 kv impulse oil circuit breaker interrupting a 132-kv 1,200-ampere short circuit

Time from trip impulse to contact separation, 2.0 cycles; to interruption, 2.5 cycles. Contact separation at interruption, 1.0 inch per break. Rate of rise of recovery voltage, 2,900 volts per microsecond

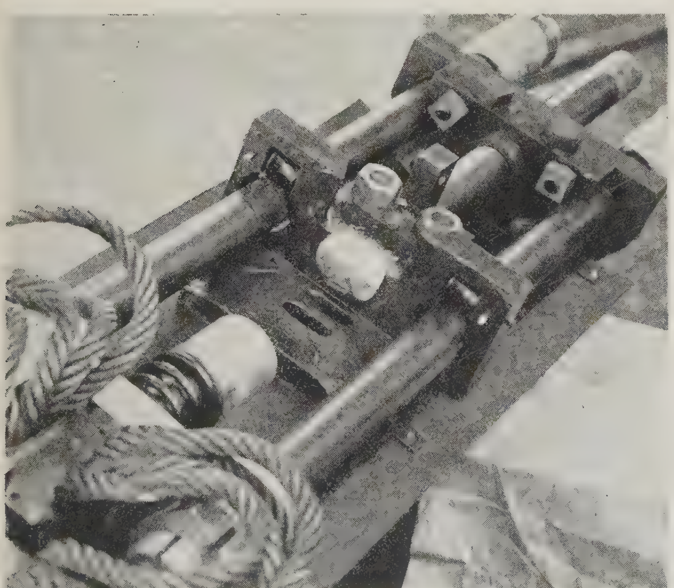


Fig. 8. Lower side of baffle showing contact and operating rod assembly and entrance of double ports. Contacts are in excellent condition after extended tests

small drain on the station battery. A permanent magnet trip of the flux shifting type gives highest speed response with no steady drain on the station battery.

Tests

The 287 kv rating carries with it a one-minute high-potential test of 650 kv. This test was made successfully with the circuit breaker open and one side grounded. After this, the voltage was raised to a flashover value corresponding to 780 kv under standard conditions. At this point the flashover occurred across one of the current transformer columns to ground, rather than across the interrupting elements. High voltage impulse tests also were made, in which the circuit breaker was flashed over by a 1×5 microsecond wave having a crest of 1,900,000 volts. As before, the flashover occurred across the outside of the current transformer columns. An extended series of interrupting tests was made, from which representative tests are given in table I. Of all other tests made but not shown in the table, none exceeded 3 cycles over-all from the trip impulse. In this table tests are shown for currents as high as 9,300 amperes, or nearly twice the interrupting rating of 5,000 amperes. The whole breaker has interrupted 264 kv, compared with 250 kv which is 0.866 times the line voltage. This same voltage has been handled successfully by half of the breaker without increased arcing time; 88 kv has been interrupted by a single break without increased arcing

time. A voltage as high as 110 kv has been interrupted by one break; this latter voltage, however, appears to indicate the ultimate capacity of one break, as in one of the 2 tests at that voltage the arcing time was extended. The average total time for all tests except the single break tests was 2.54 cycles, of which 0.54 cycle was arcing time. In 17 of the tests shown in table I, the contacts had not separated at the current zero previous to the one at which interruption occurred. The maximum arc length of all the full breaker tests was 1.5 inch per break, while for 1/2 breaker tests the arc length was 1.9 inch per break. During 47 tests, including the high current tests in the table, oil dielectric strength fell from 28 to 20.5 kv for 0.1 inch.

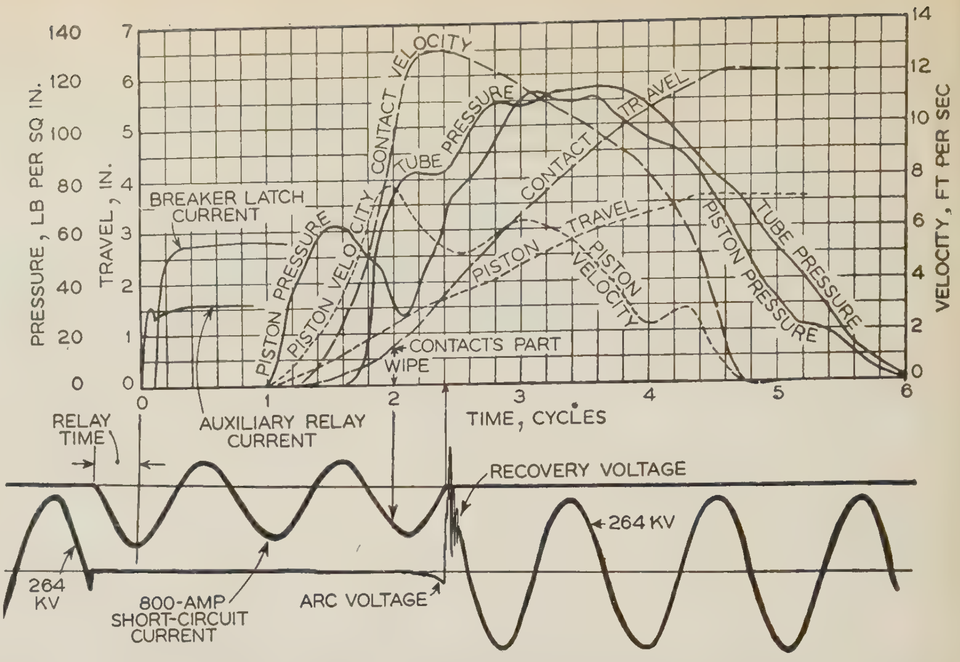


Fig. 10. Time diagram of operating characteristics of 287 kv impulse circuit breaker; time in cycles is based upon a 60 cycle system

The interrupting rating of this 287 kv circuit breaker is 2,500,000 kva. The highest single phase capacity in any of the tests of the whole breaker in table I is 300,000 kva. However, in test 100 made on one break at a voltage 50 per cent higher than one break can receive in service, 3,800 amperes was interrupted; this is equivalent to a 3 phase interruption of 1,890,000 kva on the whole circuit breaker. A further analysis of the basis of extrapolation with this type of breaker appears in the appendix.

Figure 9 shows oscillograms of a typical test showing an interruption of the circuit in $2^1/_2$ cycles. These oscillograms show the measurement of pressure and the travel of various parts. These data have been analyzed to make up the composite chart shown in figure 10, on which all of the various events have been plotted. It appears that after the trip impulse has been impressed upon the auxiliary relay, the current begins to flow in the main trip coil after 0.1 cycle. At the end of 1 cycle, motion of the major parts is observed. At 2 cycles the contacts separate, and at the next current zero, occurring in this test at 2.4 cycles, the circuit is interrupted.

Appendix—Extrapolation of Test Results

In general, the larger circuit breakers of today cannot be tested at rating in any of the existing testing plants. It is necessary, therefore, to use some basis of extrapolation, just as is done with other large equipment. The basis of extrapolation is not the same for different types of circuit breakers. Two methods of extrapolation are available for the high voltage impulse breaker which prove its high power performance with certainty, but which would not be applicable to other types without special proofs.

The potential distribution has been determined. The highest voltage appearing across one break is known. Test 100 (table I) at a voltage 50 per cent higher than the highest voltage in service was equivalent to nearly 2,000,000 kva on the whole 3 phase breaker. If there were only a few breaks, or if the voltage actually appearing across one break were not ascertainable, this method of extrapolation would not be available.

The impulse breaker has another property helpful in extrapolation that is only approached by a few other types. Arc length is constant over a wide range of test voltage. The distress in a circuit breaker is caused by electromagnetic forces, contact burning, and gas formation with the pressures incident thereto. These are determined by the arc length in time and inches. If a circuit breaker has a sufficiently positive arc extinguishing process to operate at full voltage and recovery rate, but at light currents, the question remains: Would the arc interrupting function be modified at heavy currents, and if it is not modified will the circuit breaker stand the additional punishment accompanying the heavy full rated current?

The high voltage tests of table I prove that the interrupting element will take care of the highest voltages and recovery rates with a safety factor of at least 100 per cent. At lower voltages, arc length in cycles and inches remained substantially the same, as did the oil pressures and oil velocities. Therefore, the ability to handle high voltage and high recovery rate was present even though not used. At lower voltages the current was increased to nearly double rating without altering these voltage interrupting conditions. The 9,300 amperes in test 37 is equivalent on this basis to 4,600,000 kva. It is concluded therefore, that all the distress elements were present and that the simultaneous appearance of voltage and recovery rate would have made no difference. Under these conditions, extrapolation is justified where it would not be if arc length, pressure, and other factors were variable with voltage.

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Direct Measurement of Surge Currents

A new instrument, called the surge crest ammeter, based upon the principle of magnetic retentivity has made available a direct and simple method of measuring surge currents. A study of the behavior of 2 magnetic links under the influence of oscillatory surge currents has made this instrument useful in measuring the per cent oscillation as well as crest values of surge currents. Specimen measurements included in this paper show briefly one application of this instrument.

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TO PROVIDE for a high standard of power service a great many problems related to transient or surge conditions must be met successfully. These problems concern insulation and mechanical strength and involve a great variety of circumstances. The designer must have adequate information concerning the nature of the existing transient conditions and reliable data pertaining to the surge performance of materials and apparatus arrangements. Instruments and methods of measurement adapted to the study of surge voltages and surge currents are necessary.

Throughout the early years of the era of electric power suitable surge instruments were not available. For many years the sphere gap[1–4] for measuring crest values of surge voltages was the only practical surge measuring apparatus in the hands of the engineer. Within recent years surge voltage recorders of the Lichtenberg figure type,[5–7] surge indicators,[8] and the cathode ray oscillograph[9–15] have been introduced in the form of practical working instruments applicable to surge measurements. Good progress in the field of surge measurements has been made since the introduction of these tools.

A paper recommended for publication by the A.I.E.E. committee on instruments and measurements, and scheduled for discussion at the A.I.E.E. summer convention, Ithaca, N. Y., June 24–28, 1935. Manuscript submitted Jan. 15, 1935; released for publication Feb. 26, 1935.

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1. For all numbered references see list at end of paper.

In studies of lightning strokes on transmission lines[16,17] recent developments have made it vitally important to have available a simple arrangement for the direct measurement of crest values of surge currents. A measuring instrument that would permit the location of hundreds of current measuring stations with a minimum of attention and give reasonable accuracy was required. For this purpose a surge crest ammeter based upon the principle of magnetic retentivity was conceived; it has been made practical through a series of laboratory tests and calibrations extending over a period of 3 years. Field work pertaining to measurements of surge currents was continued in progress along with this laboratory work.[16] As rapidly as instruments and methods were worked out in the laboratory, measuring stations were established in the field. Preliminary surveys of progress in the design of this instrument have been published previously.[18,19] In this early work, which pertained particularly to unidirectional polarity surges, the principles involved and technique were obvious in their simplicity and directness. Later work with oscillatory surges introduced principles and methods that are not understood quite so readily. This paper presents these recent developments including important material not published heretofore.

The principal features of the surge crest ammeter that make it ideal for measuring surge currents are:

1. It is a direct method of measurement; when properly installed the links respond only to the magnetic field present when a current flows through a conductor.
2. It is simple, and because of this a great many measuring stations can be operated at small cost per station.
3. It can be installed easily without disturbing in the least the current carrying circuit.
4. It measures current amplitude and per cent oscillation, and shows current polarity.
5. The same measuring apparatus is used repeatedly.

Principle of the Surge Crest Ammeter

Two small pieces of magnetic material having high retentivity are placed adjacent to the surge current carrying conductor at different distances as shown in figure 1. These are called the inner and outer magnetic links. When the surge current passes through the conductor the links are well within the surrounding magnetic field and are acted upon by a magnetizing force proportional to the current magnitude and inversely proportional to the distance from the conductor. The retained magnetization depends upon the magnetic properties of the link and the wave shape of the surge. However, it has been shown previously[18] that with a properly constructed magnetic link the retained magnetization using direct current is equal to that obtained with a $^1/_2$ x 5 microsecond wave of the same crest amplitude. Time is therefore not a factor for surges slower than a $^1/_2$ x 5 microsecond wave.

The magnetization of the links, of course, may be measured by a ballistic galvanometer, but this method is applicable to laboratory work only. Consequently, a simple compact portable instru-

ment was designed for general field and laboratory measurements.[19]

Laboratory Current Calibrations

In making the surge crest ammeter available for general use, a series of interesting and important laboratory calibrations were made. A surge current generator[20] was used as a source from which surges of various wave shapes were obtained.

A symmetrically constructed discharge circuit as shown in figure 2 was arranged. The use of such a circuit with the links mounted on the central vertical member eliminated the necessity for any corrections of link magnetization due to currents in the bus structure.

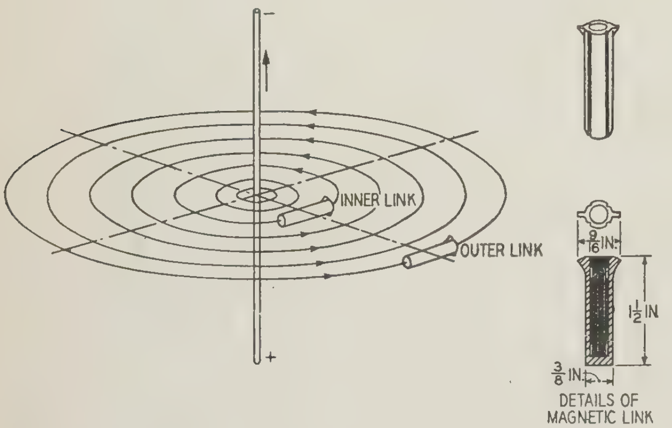


Fig. 1 (above). Principle of operation of surge crest ammeter and details of magnetic link

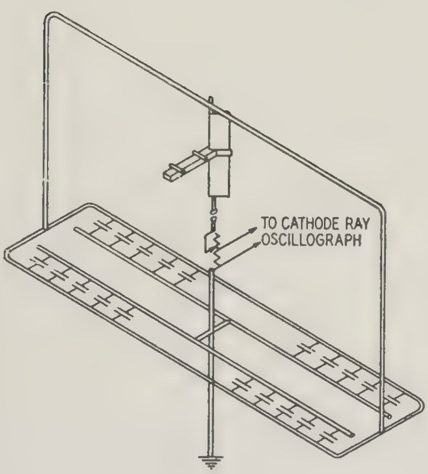


Fig. 2 (right). Connections of surge current generator and apparatus for calibrating magnetic links

The surges used varied from impulses of unidirectional polarity through a series of damped oscillations ranging up to 50 per cent oscillation. The per cent oscillation is the ratio of amplitude of the second half cycle to that of the first half cycle expressed as a percentage. Wave shapes were recorded and amplitudes measured by cathode ray oscillograph. Sample oscillograms are reproduced in figure 3. For each wave shape, current amplitudes were varied over a wide range. Several magnetic links each placed at a different distance from the current carrying conductor were exposed to each wave shape and current amplitude, and thereafter measured on the surge crest ammeter.

A specimen of test results using the waves of figure 3 at various current amplitudes is shown in figure 4. These data pertain to link positions such as shown in figure 1, wherein the inner link is 2.6 inches and the outer link 8.6 inches from the center of current. The ratio 8.6/2.6 is called the "distance ratio." In the upper curves, which show surge crest ammeter readings plotted against crest magnetizing currents, those for both inner and outer links for unidirectional surges are straight lines, showing direct proportionality between magnetizing current and surge crest ammeter readings for such surges. Readings for the outer link of course are less than those for the inner link, the ratio between the 2 being numerically equal to the distance ratio.

For oscillatory surges the curves for both inner and outer links have downward curvatures. Examination of figure 4 will show that this downward curvature is decidedly more pronounced for the inner link, which is in a more intense magnetic field. Curves for the outer link do not show downward curvature of appreciable degree over the range of currents on the abscissas until a surge of 20.2 per cent oscillation is used. For oscillatory surges, therefore, the ratios of readings for the inner link to corresponding readings for the outer link are less than the distance ratio and decrease as the percentage oscillation and current amplitudes increase. The ratios are plotted on the middle part of figure 4. Combining these ratio curves with the inner link curves gives a convenient surge measurement chart. This is done by locating and connecting points of equal ratio on the inner link curves. The inner link curves of the upper part of figure 4 are reproduced in the lower part. Points of equal ratio for each percentage oscillation are located as illustrated by the dotted lines for the 2.4 ratio. For other ratios similar points are located and lines drawn.

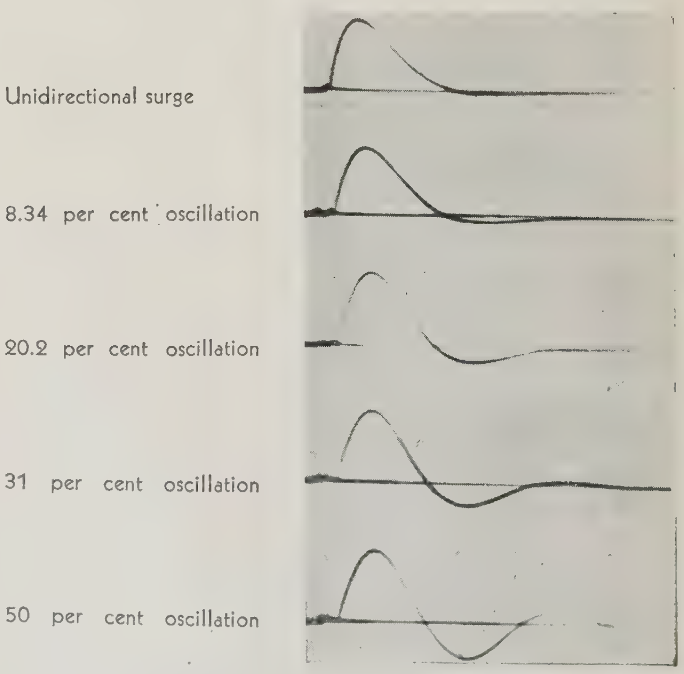


Fig. 3. Cathode ray oscillograms of surges used for calibrating magnetic links

A complete calibration chart built up exactly as just described is shown in figure 5, which is described later under the heading "Use of Calibration Charts."

Experimental Study of Magnetic Links Under Various Surge Conditions

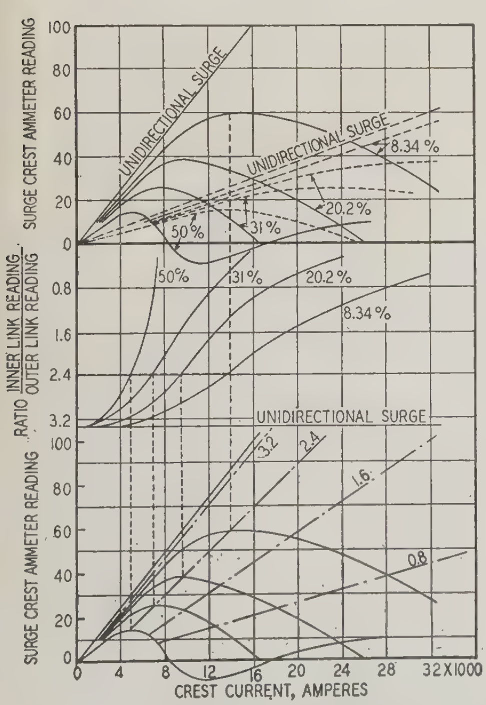
The magnetic-retentivity phenomenon upon which the method of measuring surge currents by means of the surge crest ammeter depends are demonstrated clearly by a few very simple laboratory experiments. One such experiment will be described. Eight magnetic links were mounted as shown at the lower left of figure 6 at 8 different distances from the current carrying conductor. Six unidirectional current surges with amplitudes as illustrated immediately above the bracket were used in the experiment. These surges were passed through the angle iron conductor in various combinations and surge crest ammeter readings taken after each combination, as follows:

1. Surge A applied and all links measured. Results are plotted at the top left immediately above the wave illustration. Surge crest ammeter readings are related to distance to current center, for each link. The familiar hyperbolic law of inverse proportionality of magnetizing force to distance is illustrated. A surge crest ammeter reading of 100 is obtained with a fully magnetized link. Surge A therefore gave the innermost link practically the maximum residual density it would retain. All other links obtained lower degrees of magnetization. The surge crest ammeter reading for each link was plotted also on the ordinate axis of the graph at the right of figure 6.

2. Surge A applied and immediately followed by surge F; then surge crest ammeter readings of all 8 links taken. Surges A and F were equal in amplitude, but opposite in polarity. These readings are plotted on the right hand graph of figure 6 above AF. All links were left with a magnetization practically equal to that obtained by surge A alone, but opposite in polarity.

3. Surge A applied and immediately followed by surge E, which had an amplitude of 80 per cent of the amplitude of surge A and was opposite in polarity; then surge crest ammeter readings of all 8 links were taken. These readings are plotted above AE on the right hand graph at the 80 per cent amplitude value on the abscissa.

4, 5, 6. Surge combinations AD, AC, and AB applied just as in combination 3. Surges D, C, and B had amplitudes of 60, 40, and 20 per cent of the amplitude of surge A, respectively, but were opposite in polarity. Similar points were plotted on the graph for each.



Surge crest ammeter readings for inner (—) and outer (---) links. Percentage figures on curves indicate per cent oscillation

Ratio of readings for inner link to corresponding readings for outer link for different percentages of oscillation

Final calibration curves
——Readings for inner link (repeated from top group of curves)
—·— Equal ratio lines (ratios indicated on curves)

Fig. 4. Specimen calibration of a 2-link arrangement

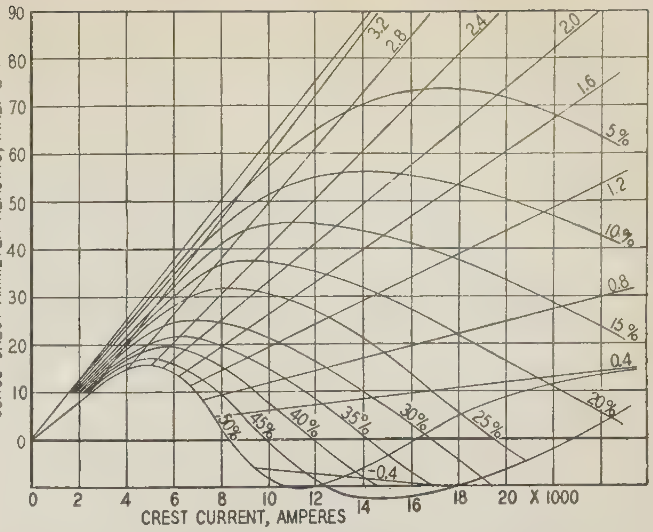


Fig. 5. Calibration chart drawn as illustrated in figure 4 for 4 inch angle iron with magnetic links at 1 and 7 inches from vertex of angle

Curves show surge crest ammeter readings for inner link for various percentages of oscillation as indicated
Straight lines are lines of equal ratio between readings for inner link and corresponding readings for outer link, for various ratios as indicated

Study of the smooth lines drawn for each link position shows very clearly that the links in the outer positions away from the conductor and operating in a weaker magnetic field require a second surge of opposite polarity of higher percentage of the first surge for the same per cent demagnetization. For instance, the link in the extreme outer position required a reversed polarity surge of 67 per cent amplitude to reduce its residual magnetization resulting from surge A to zero, while the innermost link required a reversed polarity surge of only 33 per cent for the same result. These relations are cumulative for complete oscillations of several half cycles and are responsible for the variable inner link-outer link ratios illustrated in figure 4.

If an oscillatory surge passes through the conductor the relation of magnetizing forces to link magnetization are as illustrated in figures 7 and 8. These are illustrations of hysteresis loops under oscillatory surge conditions. A magnetizing force H_m when reduced to zero leaves the inner and outer links with residual flux densities of B_r and b_r, respectively, at the end of the first half cycle. The second half cycle H_m' leaves the 2 links at B_r' and b_r'. Such a cycle follows for each half cycle of the wave. The loops for the inner and outer links finally center about particular points on the ordinate axis which are the resultant residual magnetization points after the surge has passed. In figure 7 amplitude and per cent oscillation were just right to leave both links with the same residual magnetization. This gives an inner link-outer link ratio of 1. In figure 8 the inner link was left with a reversed polarity magne-

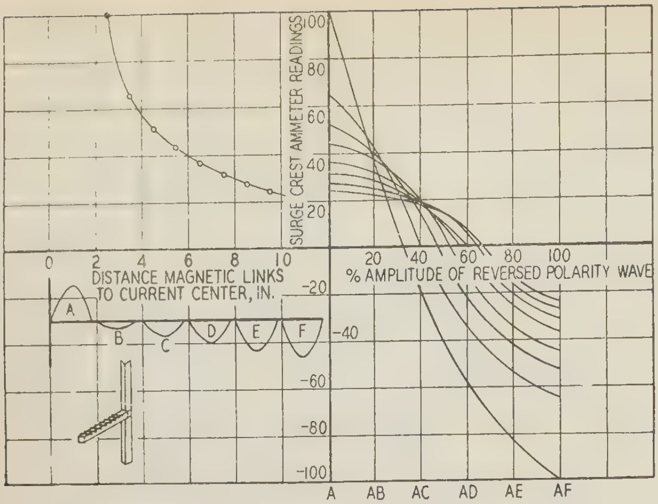


Fig. 6. Results of impulse tests on magnetic links

Lower left. Impulses applied, and sketch showing arrangement of the 8 links. Inner link 2.6 inches from center of current; distance between links 1 inch

Upper left. Surge crest ammeter readings for the 8 links after application of surge A

Right. Surge crest ammeter readings for the 8 links after application of various impulses as explained in text

tization while the outer link still retained the polarity of the first half cycle. This gives a negative inner link-outer link ratio.

Use of Calibration Charts

Keeping in mind the magnetic phenomenon illustrated, it is apparent that the resulting magnetizations for any link at any distance from a conductor will depend upon 3 factors: (1) the current amplitude, (2) the per cent oscillation, and (3) the distance from link to current center. For each link of the standard 2-link installation these 3 factors also determine the residual magnetization, but their relative influence on the 2 links is different as has been shown.

The third of these factors always is known, being deliberately chosen to permit readings over the range of currents to be measured. Provided the surge has a constant per cent oscillation, the current amplitude and the per cent oscillation may readily be read from the calibration chart of figure 5 in accordance with the following example: Assume an inner link reading of 36 and an outer link reading of 15; the ratio is 2.4. Reading at 36 on the surge crest ammeter ordinate scale across horizontally to the sloping ratio line marked 2.4 gives the reference point. Reading directly below on the abscissa scale gives a crest current of 9,000 amperes. Interpolation between the curved per cent oscillation lines gives an oscillation of 22 per cent. The second half cycle therefore has a crest value 22 per cent of 9,000 or 1,980 amperes. Each succeeding half cycle is 22 per cent of the preceding one.

Field Records

Use has been found for this direct method of measuring crest values of surge currents in the factory, field (see reference 16, Part IV), and laboratory. A total of approximately 10,000 magnetic links, constituting 5,000 measuring stations were in operation during 1934. The greatest number of records have been obtained on transmission line structures under lightning current conditions. Measurements have been obtained of lightning currents in tower legs, tower top lightning rods, counterpoise cables, and tower arms. Specimen records from each of these are given in table I.

The value of such records is revealed in the samples given. The single-leg currents in adjacent towers at the top of the table show lightning currents flowing through 5 adjacent towers. The currents in the legs are shown to be oscillatory with a second half cycle averaging about 27 per cent of the first.

The 4-leg readings next below show a current of 30,000 amperes dividing into 7,000 amperes per leg quite evenly. Below this set of readings is given a 4-leg reading for a case in which 2 of the legs were connected to parallel counterpoise grounding cables. The counterpoise legs carried 12,000 amperes against 7,000 for the free legs.

Samples of direct counterpoise cable readings for both radial and parallel counterpoise cables are given in the center of the table. For the radial counterpoise it may be noted that the 150 foot cable carried more than twice the current of the 40 foot cable. For the parallel counterpoise, with measuring stations located along the cable, measurements of currents at different distances from the towers give information on the effectiveness of the counterpoise in reducing tower potentials. The tower arm measurements give information pertaining to insulator flashover and, when coupled with readings in other parts of the

Table I—Records of Some Typical Measurements Made in the Field With the Surge Crest Ammeter

Types of Installations		Surge Crest Ammeter Readings: Inner Link	Outer Link	Ratio	Current in Amperes	Per Cent Oscillation	Remarks
Single-leg currents in adjacent towers		25	12	2.08	8,600	33	
		44	20	2.2	12,900	18	
		17	10	1.7	7,800	44	
		42	17	2.47	10,900	17.5	
		32.5	15	2.17	10,200	25	
4-leg single-tower readings	Tower 1	18	11	1.64	7,200	39	Radial counterpoise: 4 50-ft cables
		16	11	1.45	7,800	40	
		27	12	2.25	7,500	28	
		20	12	1.67	7,700	36	
	Tower 2	20	11	1.82	7,700	37.5	No counterpoise
		20	10.5	1.9	6,900	38	
		54	22	2.46	12,100	10.5	Parallel counterpoise
		75	23	3.26	12,100	1	
Radial counterpoise		32	11	2.91	2,600	11	40 ft, 223 ohms
		75	23.5	3.19	5,700	0	150 ft, 118 ohms
Parallel counterpoise		32	5	..	2,400	..	From 4 legs of tower in one direction
		21	T	..	1,600	..	
		11	T	..	800	..	
		T	0	..	400	..	
		23	9	2.56	2,400	27.5	From 4 legs of same tower in opposite direction
		20	1	..	1,500	27.5	
		11	8	1.37	3,200	44	
		14	9	1.55	3,100	42	
Tower arm		56	..	..	18,000	..	Approx. currents
		100	..	..	32,000	..	Indications of flashover
Lightning rod		−58	−68	*	13,500	*	*Both links at same distance from current center
		−60	−56	*	12,400	*	
		+64	+64	*	13,800	*	
		−68	−68	*	17,000	*	

structure, show whether the conductor or tower structure was struck.

The lightning rod measurements at the bottom of the table I were not obtained by the method that permits per cent oscillation to be determined, and therefore may be in error if the stroke current in the rod was oscillatory.

Accuracy

The accuracy of a current measurement by the surge crest ammeter-magnetic link method depends upon 3 things as follows:

1. The magnetic link. How much does the magnetizing force-retentivity curve for the particular links used in the measurement depart from the average curve on which the calibration curves were based?

2. The surge crest ammeter. How much do the scale readings of the particular surge crest ammeter used depart from the true magnetizing force-scale deflection relation arbitrarily chosen to make scale reading proportional to magnetizing current?

3. The magnetic link field installation. How greatly do the dimensions such as link distances depart from those distances on which calibrations used were based?

When these 3 questions are answered the degree of accuracy of measurement is known. The dimensional characteristics of the field installation referred to in question 3 are believed not to introduce inaccuracies greater than 3 per cent except where links are located inside 2 inches from a conductor. Discrepancies in distance may be eliminated readily by the use of bracket arrangements giving precise spacings.

The maximum tolerance for the surge crest ammeter deflection at calibration referred to in question 2 is 3 scale divisions between 10 and 80 and 5 scale divisions between 80 and 100. Two links always are measured for every standard reading. This gives a 2 point reading, usually a midscale and an end-of-scale reading both of which influence the final accuracy.

The principal factor governing accuracy is referred to in question 1—variations in the magnetic link. Magnetizing force-retentivity curves are not the

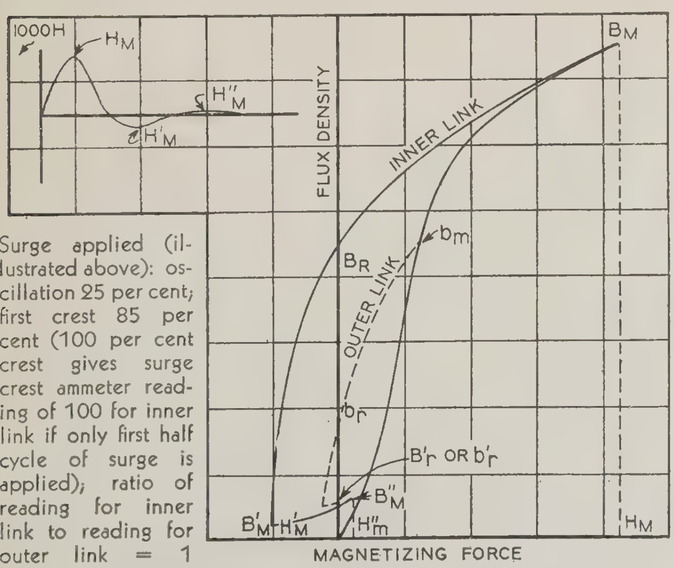


Fig. 7. Magnetization loops for inner and outer links for an oscillatory surge

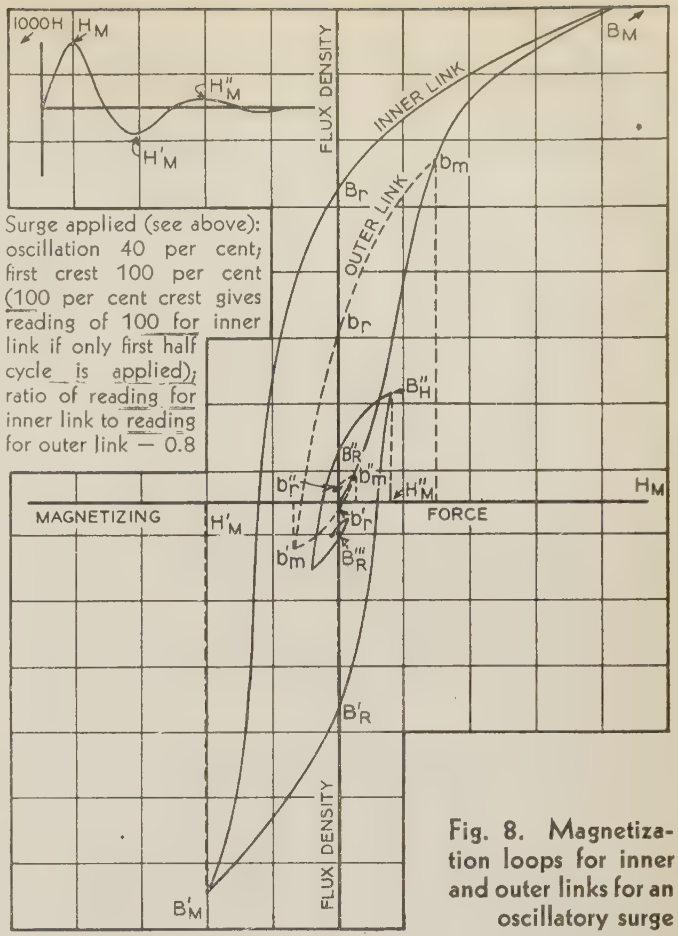


Fig. 8. Magnetization loops for inner and outer links for an oscillatory surge

same for all magnetic links. Considerable progress has been made in controlling this characteristic, and by selection links can be obtained having the same curves.

For general field work, particularly in lightning measurements where hundreds of stations are used, it is agreed that efforts to measure to accuracies better than 10 per cent are of questionable value. Magnetic links therefore are selected by test to achieve over-all results within this range, and present control of the steel characteristic makes this possible without serious loss.

If greater accuracies are required, continued link selection will permit an improvement of the accuracy down to that of the surge crest ammeter. If still greater accuracies are required, a precision ballistic galvanometer may be used to measure links. Working accuracies in the order of 1 per cent are possible through the use of precise links and measuring methods.

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Armature Leakage Reactance of Synchronous Machines

An extension of the Potier method of testing for armature leakage reactance of synchronous machines is presented in this paper, wherein it is shown that the easily tested for Potier reactance varies considerably and therefore has a limited field of usefulness. It is further shown that if the Potier reactance is measured at high values of field current, the armature leakage reactance is closely approximated and a more valuable test results.

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An accurate knowledge of the armature leakage reactance of synchronous machines is essential to the designer who must calculate the flux densities in the various magnetic paths of a synchronous machine. It is also of interest to the operating engineer who must determine the operating characteristics, such as the short-circuit currents and the increasingly important steady-state stability limits,[6] which are appreciably affected by synchronous machine saturation. To meet the need of the designers, P. L. Alger[3] presented in 1928 formulas for armature leakage reactance. In 1931, L. A. Kilgore[4] proposed other formulas. These formulas provided a rational method by which the leakage reactance could be calculated. No matter how important a knowledge of this leakage reactance is for the proper determination of machine characteristics, this reactance could not be fully utilized generally as long as there existed only a method of calculating it from design data and there did not exist a practical method of testing for it. As a result, the easily tested for Potier reactance[1,5] at normal voltage has been used generally instead of leakage reactance to calculate the performance of machines, notwithstanding the fact that Potier reactance at normal voltage may differ considerably from the armature leakage reactance as defined by Alger and Kilgore.

The purposes of this paper are: first, to show that Potier reactance varies considerably with magnetic loading and consequently when measured by the standardized method[5] at normal voltage has a very limited field of usefulness; and second, to show that, if Potier reactance is measured at high values of field current, it gives a value which closely corresponds to armature leakage reactance and thus offers a more accurate method of obtaining a test value of this important reactance.

Theoretical Analysis

In the following analysis the characteristics of a synchronous machine at no load and at rated current zero power factor will be used to determine the leakage reactance. The armature leakage reactance is defined as the reactance due to the difference between the total flux (effective in producing fundamental terminal voltage) produced by the armature current acting alone and the space fundamental of the flux in the air gap produced by the same armature current.[3,4] Neglecting the armature resistance voltage drop, only direct axis quantities therefore need be considered. This accordingly assumes that the leakage reactance of a machine is determined by the direct axis leakage fluxes, while actually there is some difference, though generally small, in the amount of armature leakage flux (due chiefly to a

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6. For all numbered references see list at end of paper.

change in the tooth tip leakage flux) depending upon whether the armature magnetomotive force is acting along the direct or quadrature axis.

Nomenclature. The nomenclature used in this paper is as follows. All quantities are expressed in per unit (instead of per cent) of the machine normal kilovoltampere and voltage base and correspond wherever possible with established nomenclature.

e_d = voltage corresponding to direct axis field magnetomotive force
e_l = voltage corresponding to the air gap flux (behind leakage reactance)
e_p = voltage behind Potier reactance
e_t = terminal voltage
i = armature current
$k = 1 + \dfrac{\text{iron magnetomotive force}}{\text{air gap magnetomotive force}}$
x_d = direct axis synchronous reactance
$x_{ad} = x_d - x_l$ = direct axis armature reaction reactance
x_l = leakage reactance
x_p = Potier reactance

Assumptions. Following are the assumptions which have been made for the theoretical analysis of this problem.

1. The armature reaction magnetomotive force is proportional to a reactive voltage drop equal to $(x_d - x_l)i_d$.

2. The difference between the armature reaction magnetomotive force at zero power factor and the magnetomotive force due to the field current is a magnetomotive force which is proportional to k times the voltage behind the leakage reactance drop. Where,

$$k = 1 + \frac{\text{iron magnetomotive force}}{\text{air gap magnetomotive force}}$$

3. Armature leakage reactance is independent of saturation. This assumption is generally justifiable as an appreciable part of all of the armature leakage flux paths are in air.

In accordance with the above assumptions the following expression can be written for the field magnetomotive force at zero power factor.

$$e_d = (e_t + ix_l)k + (x_d - x_l)i \quad (1)$$

Figure 1 presents a no-load saturation curve a and a zero power factor normal current saturation curve b for a synchronous machine. The curve c represents a load saturation curve constructed from curve b and a triangle having synchronous reactance x_d, as its base and the leakage reactance x_l as its altitude, with one side parallel to the air gap line. This triangle corresponds exactly with the well-known Potier triangle except that leakage reactance is used instead of Potier reactance. This triangle expresses equation 1 graphically. Hereinafter, this triangle will be called the leakage reactance triangle. The load saturation curve c has, therefore, iron plus air gap magnetomotive force as abscissa and a voltage corresponding to the fundamental air gap flux e_l as ordinate.

The load saturation curve c has the same or greater

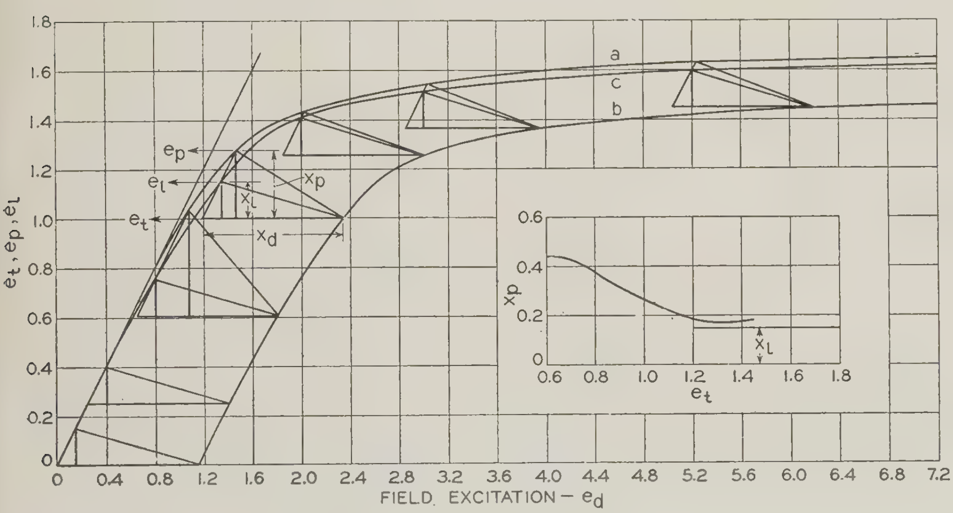

Fig. 1. Calculated saturation characteristics for a machine with very little pole body saturation at low field currents

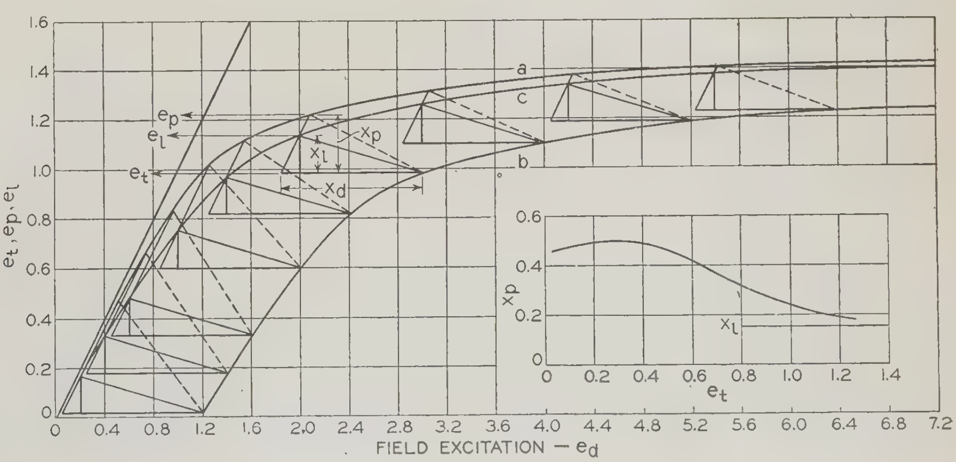

Fig. 2. Calculated saturation characteristics for a machine with an appreciable amount of pole body saturation at low field currents

magnetomotive force than the no load saturation curve a for the same air gap voltage, as the iron magnetomotive force necessary to obtain the same fundamental *air gap flux* is greater with increased armature reaction and field current. That is, the saturation factor k is not only a function of the air gap flux e_t but also of the total field current e_d.

This difference between the load saturation curve as constructed by the leakage reactance triangle and the no-load saturation curve can be attributed mainly to 2 effects: (1) increased rotor saturation due to the increase in field leakage flux with increase in armature reaction for the same useful air gap flux; and (2) any change in the air gap flux wave form due to armature reaction which changes the final required magnetomotive force.

As the field current increases, on open circuit, the voltage rises more and more slowly (curve a) until at very high field currents the voltage becomes nearly constant, the flux being limited by saturation. If now full load zero power factor armature current is maintained while the field current is again increased (curve c), the additional field leakage due to the increment in field magnetomotive force equal to a magnetomotive force $i_d\ x_{ad}$ is at first important, causing curve c to dip well below curve a.

However, under saturated conditions as the field current is increased the additional field leakage flux, caused by the addition of a field magnetomotive force equal to $x_{ad}\ i_d$, becomes increasingly, (1) less in magnitude, as well as, (2) a smaller proportion of the total flux. Hence, the 2 curves approach each other vertically, although they become displaced horizontally. Since Potier reactance is measured by the altitude of the Potier triangle, it follows that Potier reactance can be expected to decrease with high values of field current and approach as a limit (if leakage reactance itself is not affected by saturation) armature leakage reactance as defined by Alger and Kilgore.

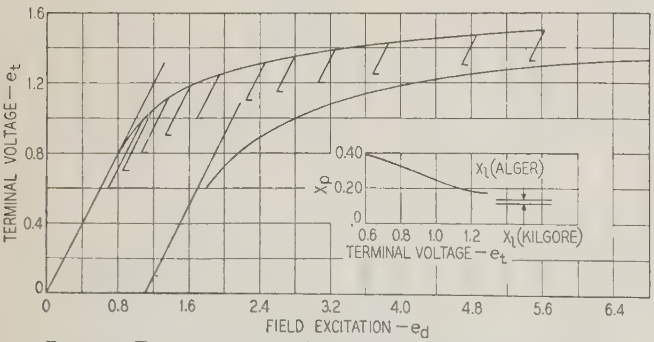

Fig. 3. Test saturation characteristics for a small high speed salient pole water wheel driven generator

Figures 1 and 2 represent 2 extreme cases which, although for fictitious machines (calculated curves), illustrate the difference in shape of the Potier reactance versus terminal voltage characteristics which may be obtained. Figure 1 is for a machine which has very little pole body saturation at normal field currents while Figure 2 is for a machine which has an appreciable amount of pole body saturation even at low values of field current.

In the case of figure 1, Potier reactance actually increases slightly after having decreased almost to leakage reactance. Also for the case of figure 1, Potier reactance approaches very closely to leakage reactance at a terminal voltage not much greater than normal ($e_t = 1.0$). It is evident from figure 1 that Potier reactance x_p should be measured well above the knee of the saturation curve, even when the load saturation is small.

Although both cases represent limiting conditions, they illustrate the tendency for Potier reactance to approach leakage reactance at the high values of saturation. If armature leakage reactance itself is reduced by saturation, Potier reactance will tend to approach a value less than the value of armature leakage reactance as calculated by the formulas of Alger and Kilgore. The value which it approaches under these conditions may be considered a saturated value of leakage reactance. However, based upon calculations, it is not expected that the ratio of the saturated value of leakage reactance to the unsaturated value will vary appreciably from unity except at extremely high values of saturation.

Test Results

Tests were made on 4 salient pole machines and on 1 cylindrical rotor machine to determine the variation in Potier reactance with change in magnetic loading. The results of these tests are shown on figures 3 to 7, and are tabulated in table I.

Table I—Results of Tests on 5 Machines

Type of Machine*	x_l (Alger)	x_l (Kilgore)	$x_l = x_d - x_{ad}$ (x_d Tested, x_{ad} Calculated)	x_p (Lowest Value From Test)	x_p (Test Value Obtained at Normal Voltage)
Fig. 3	0.14	0.115	0.125	0.17	0.244
Fig. 4	0.16	0.155	0.175	0.16	0.19
Fig. 5	0.10	0.082	0.075	0.12	0.205
Fig. 6	0.10		0.08	0.168	0.216
Fig. 7	0.10	0.15	0.130	0.13	0.155

* Machine types are as follows:
Fig. 3. Small high speed salient pole water wheel driven generator.
Fig. 4. Large slow speed salient pole water wheel driven generator.
Fig. 5. Large 25 cycle salient pole water wheel driven generator.
Fig. 6. Small high speed salient pole synchronous motor.
Fig. 7. Small 2 pole cylindrical rotor steam turbine driven generator.

The test results show the variation in Potier reactance with increase in field current. All these tests bear out the theoretical conclusion for the case of salient pole machines that Potier reactance approaches, as a limit at high values of saturation, leakage reactance. For the cylindrical rotor machine Potier reactance is practically constant. This is the result to be expected as a cylindrical rotor machine has a comparatively small amount of field leakage flux and distortion of the flux wave shape. The test values of Potier reactance for this cylindrical rotor case lie between the values obtained by Alger's and Kilgore's formulas. Neither Alger's nor Kilgore's formula takes into account the change in end leakage flux due to a change in the relative position of the

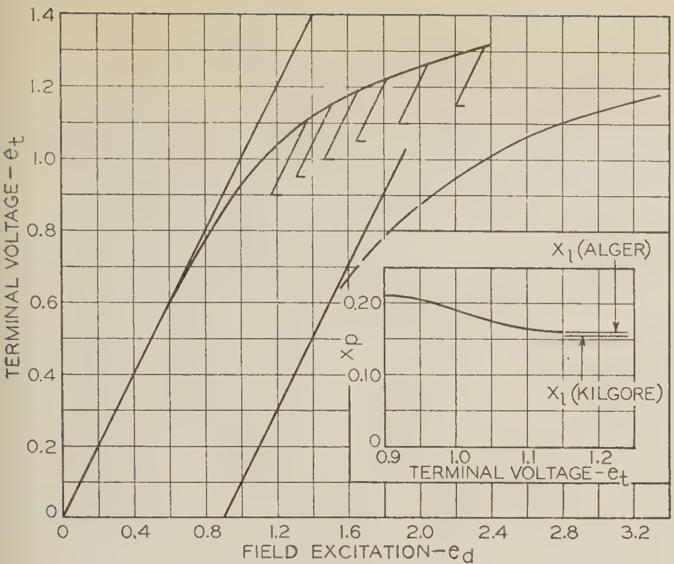

Fig. 4. Test saturation characteristics for a large slow speed salient pole water wheel driven generator

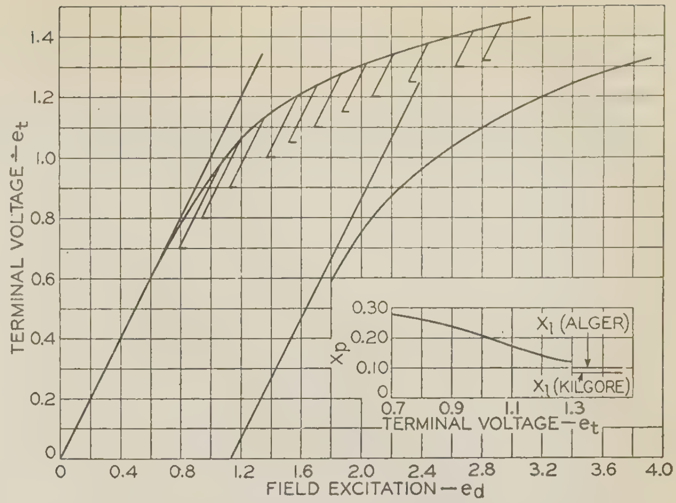

Fig. 5. Test saturation characteristics for a large 25 cycle salient pole water wheel driven generator

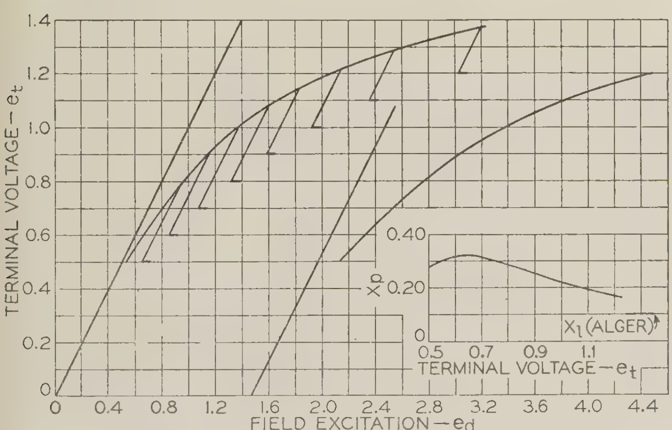

Fig. 6. Test saturation characteristics for a small high speed salient pole synchronous motor

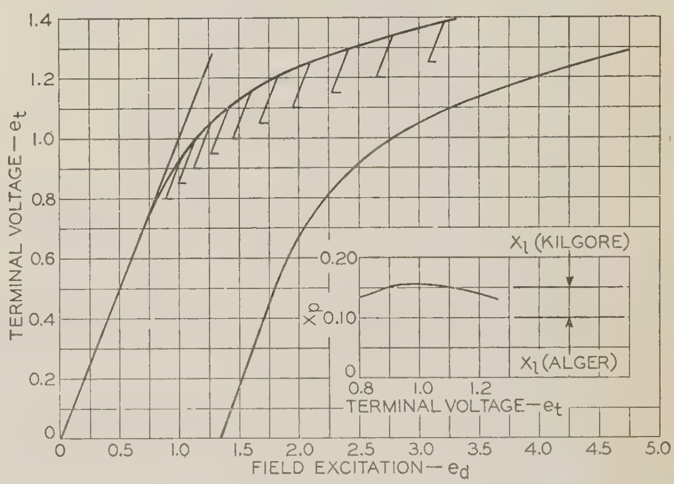

Fig. 7. Test saturation characteristics for a small 2 pole cylindrical rotor steam turbine driven generator

retaining ring and core. This relative position has been shown by tests to have considerable influence on the end leakage flux. Since in 2 pole turbine generators the end leakage reactance is relatively high compared to the total leakage reactance, it is not surprising that 2 formulas with arbitrary assumptions regarding end leakage should give such different results.

Summary

The following conclusions can be drawn from the above analysis and tests:

1. Potier reactance measured at normal voltage is not a true indication of leakage reactance and may be over 100 per cent too large. Potier reactance measured below normal voltage may be several times the leakage reactance.

2. Since Potier reactance more nearly approaches leakage reactance at high values of field current than at the normal voltage point, it is recommended that leakage reactance be measured by the Potier method at as high a value of field current as practical.

3. Because of the comparatively small amount of field leakage flux and distortion of the flux wave shape with increased armature reaction of cylindrical rotor machines which have a few number of poles, the Potier reactance of cylindrical rotor machines does not vary as much as that of salient pole machines of normal design.

4. Armature leakage reactance, for normal armature current, appears to be sensibly independent of saturation even for stator tooth densities well above practical operating values. This is evident since, with the exception of the cylindrical rotor machine, in no case does Potier reactance x_p drop below the calculated value of leakage reactance x_l.

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Cable Sheath Corrosion —Causes and Mitigation

The causes and mitigation of telephone cable sheath corrosion are dealt with in this paper, which describes particularly a method of applying a counter potential to the cable sheath for the mitigation of corrosion from localized currents. This method, although not new, has had but limited application. It may find extensive future use for controlling corrosion on intercity toll cables, and in localities where street railways have been abandoned. In addition to a unique application of this method, there is also described the method of correcting by current drainage a particularly bad case of corrosion from stray current.

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THE usual corrosion problem on telephone cables is the control of stray earth current from electric railways. The solution of this problem may be accomplished by limiting the stray current picked up and by providing drainage by means of metallic conductors from the cable to suitable points of lower potential. This quite frequently requires the coöperation of several utilities operating underground plants. Stray current from electric railways, if controlled, serves to protect the cable plant from corrosion. In the absence of stray current, localized current corrosion may become a serious problem. In this case the corrosion may be greatly reduced by a convenient and economical method of applying counter potentials.

Causes of Corrosion

Corrosion of lead cable sheath, and also corrosion of other metals, may be considered as an electrochemical process in which metals tend to go into solution at anodic points or areas. These anodic areas may result from stray direct current from electric railways or, infrequently, from other multigrounded direct current systems, such as the Edison 3 wire system. They also may result from localized currents which cause some portions of the sheath to be more electropositive with respect to the ground water electrolyte than other portions of the sheath or other metal in electrical contact with the sheath. In discussing briefly the various causes of corrosion on underground cables, stray earth currents will first be considered. The return current from a grounded electric railway system divides between the rails and earth. In a typical case, it leaves the rail at outlying points and returns to the rail or bus near the point of supply, traveling between these points through the ground and intervening metallic subsurface structures, including telephone cable sheaths. The factors controlling the amount and distribution of stray current are rail potential drop, rail insulation to earth, and earth conductivity. The last factor is influenced by the distribution and resistance of metallic subsurface structures. The sheath to earth potentials are negative in areas where the stray current is picked up, and are positive where the stray current is discharged to earth. Corrosion occurs where the sheath is positive with respect to earth and the rate of corrosion is determined by the amount of current per unit area discharged into the earth.

Chemical corrosion from a soil depends primarily upon the presence of certain dissolved materials in the ground water electrolyte. Corrosion from acetic acid deserves special mention as the process is regenerative and is similar to that used in the manufacture of commercial white lead, in which the acetic acid is released repeatedly to attack the lead anew. Thus small quantities of acetic acid may become a serious hazard. Free lime may be deposited on the sheath by water seeping through concrete used in the construction of manholes and duct lines. Lime water, which is somewhat corrosive to lead and sometimes results in considerable damage, may be present in a duct as a result of water seepage through new concrete used in the construction of manholes and duct lines. Under a comparatively rare combination of circumstances, corrosion may be caused by the presence in the soil of certain alkalies which may be deposited on the cable in locations where the potential to earth is highly negative. Lead may be corroded by the presence of water with dissolved carbon dioxide and oxygen.

Galvanic potentials causing corrosion may be set up between a metal and an electrolyte whenever the metal is immersed in the electrolyte. This potential varies with different metals and alloys and also with the character and concentration of the electrolyte. If 2 dissimilar metals in an electrolyte are electrically connected the resulting current flow will cause corrosion of the anode. If the ground water is alkaline, the lead cable may corrode as a result of the galvanic couple set up by contact with iron hangers, ladders, or loading coil cases. If the concept of galvanic potentials from contact of 2 dissimilar metals immersed in an electrolyte is extended to include potentials from variations in composition or

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condition of the sheath, then this condition is known as local action. Lead under mechanical strain, which may be caused by a scratch or dent in the sheath, may become anodic to the lead not under strain, with resultant corrosion of the anodic area. Corrosion also may be produced by variations in sheath compositions over minutely small areas.

Anodic conditions also may be set up by differences in dissolved oxygen content of the electrolyte. Portions of the sheath more or less shielded from the dissolved oxygen by contact with clay particles or other shielded portions, such as at the bottom of corroded pits, may become anodic with respect to other portions of the sheath, with resultant corrosion.

If different portions of the sheath are in contact with electrolytes which differ in character or concentration, a "concentration cell" will be formed with resultant corrosion in the anodic area. The "concentration cell" may exist over comparatively small distances, or, as in long cables or pipe lines,[1] the anodic and cathodic areas may be separated by several hundred feet.

It may be noted that the above causes of corrosion on lead sheath tend to localize the corrosion in small anodic areas and produce the phenomenon known as pitting. The metal at the bottom of the pit becomes more anodic to nearby areas by being shielded from oxygen and causes the corrosion to proceed more rapidly, at least for a period of time.

Indications of Corrosion Damage

There are no reliable methods which can be used universally to determine quantitatively the presence of corrosion damage on underground cables, except by actual inspection. This is, of course, impractical except for special tests, and therefore other means which give qualitative results are used. The usual electrolysis survey consists in making either indicating or 24 hour recording tests of the potential between the sheath and a lead electrode placed in the ground. Positive potentials generally are considered as indicative of the presence of conditions which may cause corrosion. Potential measurements are of considerable advantage in most cases of stray current electrolysis as the sheath to earth potentials usually are more than 0.1 volt. Where the potentials are less than this amount, particularly in the absence of nearby street railway systems, potential measurements may have practically no significance because the lead testing electrode has its own single potential, which is included in the measurement. In addition to potential tests, the usual electrolysis survey includes measurements of current flow along the cable sheath. This is particularly useful in the study of mitigation measures for stray earth currents. Over-all potential drop measurements are also of considerable value.

In the absence of stray direct currents, localized current on the cable sheath usually is too small to measure without special methods, and may be of little value even if known. Measurements of the current discharged into the earth and earth resistivity tests, made by means of an earth current instrument[2] are of value in special tests. However, this instrument seldom is used because of practical difficulties in its application on telephone plant.

Other indications of corrosion include the visual inspections of cables in manholes or cables withdrawn from the ducts for various reasons, or periodical examinations of short sections of cable inserted into the ducts as pilots.

Mitigation of Corrosion

The electrochemical theory of corrosion now is accepted generally as the one which best explains the multitude of facts concerning corrosion. This theory proposes that all corrosion is accompanied by a transfer of electricity between anodic and cathodic areas. This entails that there be an electrolyte and an electric potential to maintain the reaction. In the absence of any external influence, this potential is supplied entirely by the algebraic sum of the solution potentials of the anodic and cathodic areas, which net potential adjusted for the effects of polarization tends to drive the metal into solution. The solution potential of lead depends upon the character and concentration of the electrolyte. The rapidity and amount of corrosion depends, in addition to the solution potentials, upon numerous important secondary factors. The significant fact is that the solution potential, and consequently the rate of corrosion, may be either increased or decreased by the application, in the proper direction, of external potentials.

Thus 2 methods are available for the reduction of corrosion on underground cable. One is to maintain the cable free from moisture and contact with the ground water; the other is to maintain the cable slightly negative to the ground water with which it

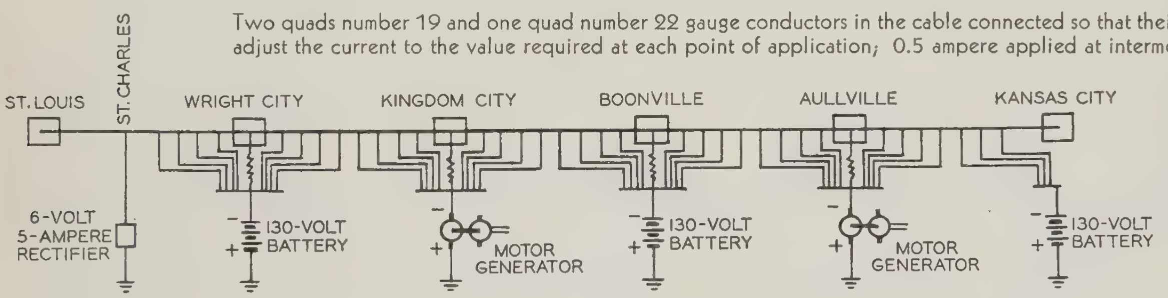

Fig. 1. Schematic diagram of electrolysis mitigation system, St. Louis-Kansas City toll cable

1. For all numbered references see list at end of paper.

is in contact. It is doubtful if it would be possible to prevent, absolutely, all corrosion under all circumstances by making the metal negative to the electrolyte. However, it is believed that if the underground cable sheath is maintained consistently negative to the surrounding earth, corrosion, under ordinary conditions, should be so reduced as not to shorten appreciably the life of the cable. This statement is well borne out by the fact that there is practically no evidence of anodic corrosive damage on cable plant maintained negative to earth by stray current.

All but a very small percentage of telephone underground cables are lead-antimony sheath cables installed in vitrified clay conduit so that they are protected from direct contact with the earth. The conduit system is constructed to drain, as completely as possible, water which seeps into the duct. In special cases protective coatings of insulating material may be used to provide additional insulation to the sheath, and in recent years there have been some installations of tape armored and jute covered cable buried directly in the earth. From a limited amount of experience with these types of cables, it appears that corrosion will be somewhat less for comparable conditions than for lead sheath cable in tile duct.

The reduction of stray current leakage from electric railways is an important detail of mitigative measures. If uncontrolled, stray direct current on cable systems may cause very serious electrolytic corrosion damage, but if properly controlled it becomes possible to maintain the cable system negative to earth and reasonably free from corrosion. The stray current picked up by the cable systems should be reduced to a minimum by avoidance of incidental or accidental contacts or close proximity of cable sheaths to other metallic structures from which current might be collected.

The stray current usually is drained from the cable system by means of a metallic bond to some point of lower potential on the railway negative return system, but preferably not to the rails. The current drained from the system should be the minimum which will maintain the entire cable system negative to earth. If there are other cable or pipe systems in the vicinity, care must be taken not to cause positive conditions on these plants. The best engineering solution in such cases may be a coöperative drainage scheme. Competitive drainage by several utilities usually results in poor economies and ineffective drainage.

Cable systems which cannot be maintained negative to earth by picking up stray current are subject to possible corrosion by localized currents. A practical and economical method of mitigating corrosion in certain of these cases is to apply a potential to the cable system to maintain it slightly negative to earth. This method has complications in its use in certain parts of cities where there is close proximity to the underground plants of other utilities and where the number of telephone cables is large.

The general method of applying counter potentials to a cable system is to ground the positive side of a suitable direct current source and connect the negative side to the cable sheath. The ground should have a low resistance at all times, being of such size and material as to withstand the resultant corrosive effects without appreciable deterioration over a reasonable period of time. The direct current source may be the central office battery, in which case the potential would be applied to the cable sheath using pairs in the cable brought out at suitable intervals, or the source may be local batteries, rectifiers, or generators installed at convenient intervals along the cable. Under favorable conditions the extent of the spread along the cable of the counteractive effect of negative current application to the sheath is remarkable. As an example, in actual practice a current of 0.75 amperes was found in a specific case to maintain about 8 miles of cable at least 0.1 volt negative to earth, whereas the previous potential ranged from 0.01 to 0.20 volt positive to earth.

As has been pointed out elsewhere in this paper, cable systems which are not influenced by stray direct current may exhibit small positive potentials to earth, which does not necessarily mean that corrosion is taking place. For such cases it has been the practice to observe conditions carefully and, if there is definite evidence that corrosion is taking place, the desirability of applying counter potentials is considered.

Two outstanding corrosion problems and their solutions will be cited to illustrate the methods described. The first involves the St. Louis-Kansas City toll cable on which some corrosion was noted in manholes soon after the cable was installed. A unique system of counter potentials was placed in operation and apparently has succeeded in stopping the corrosion. The description of the extensive electrolysis mitigation system placed in effect at Wichita, Kan., to correct a very bad condition resulting from stray earth current from the street railway system is then given.

St. Louis-Kansas City Toll Cable

This intercity toll cable was installed in 1930. It is a lead-antimony sheath cable, $2^5/_8$ inches in diameter, and was placed in vitrified clay conduit along the shoulder of U.S. highway number 40. Manholes are spaced about 750 feet apart and 4 intermediate repeater stations are spaced approximately 50 miles apart. Steel loading coil cases are installed in manholes at 6,000 foot intervals.

Several metallic drainage connections between the cable sheath and other points of lower potential were made in Kansas City and St. Louis to control the stray current from electric railways. This resulted in making the cable negative to earth for a few miles beyond the city limits of both cities. The remaining 225 miles of the cable was found to be positive to earth in nearly every manhole. The potentials ranged from 0.01 to 0.20 volt and were virtually constant at any point of test. A few scattered manholes tested slightly negative to earth. In most manholes the current on the sheath was only a few milliamperes, and there was no consistency in the direction of current flow. A few currents of

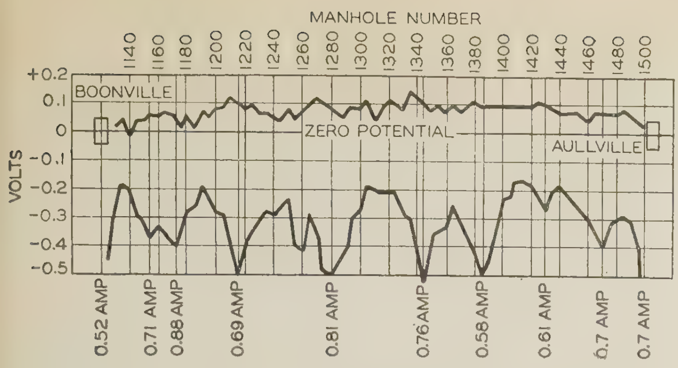

Fig. 2. Electrolysis conditions in Boonville-Aullville section, St. Louis-Kansas City toll cable

Upper curve positive to earth; lower curve negative to earth. Negative conditions result from applying negative direct current from repeater offices in amount shown at each point

magnitudes as high as 100 milliamperes were noted.

It appeared desirable to investigate the potential from cable to earth in the duct line. By means of a duct exploring electrode potentials of the same general magnitude as those noted in the manholes were observed. In several sections positive and negative conditions alternated every few feet and sometimes in less than one foot.

Several duct electrodes consisting of 6 foot lengths of lead-tin cable sleeving were installed in a duct adjacent to the cable and bonded to the cable by an insulated copper wire. The duct electrodes were removed for visual inspection 3 months after they were installed. All electrodes showed some evidence of corrosion. On some pits about $^1/_{32}$ inch in depth were found, while in others, particularly in drier locations, the corrosion was extremely slight. Earth resistivity tests were made near the manholes where the duct electrodes were installed and at numerous other points, but there seemed to be no relation to the potential of sheath to earth. It was noted, however, that at the point where the greatest damage occurred to the test electrode the lowest earth resistance also was shown. The cable was uncovered at 2 locations where it was believed corrosion might be found. From 15 to 20 feet of cable was examined and in both cases corrosion was found, but always on the bottom of the cable. Some of the pits were approximately $^1/_{32}$ of an inch in depth. All manholes were inspected and very little evidence of corrosion was found on the cables, but severe corrosion was evident on some of the spare lead-tin splicing sleeves which had been under water. The more severe corrosion on the splicing sleeves than on the lead-antimony cable sheath proper probably was caused by relatively large galvanic potentials set up on the sleeve because of its heterogeneity.

This toll cable represents a large investment and is extremely important from a service standpoint, so that in view of the evidence of corrosion along the cable it seemed desirable to install remedial measures as soon as practicable. It appeared that to obtain complete protection for this cable the most practical solution was to apply a system of counter potentials. Consideration was given to using low voltage rectifiers or wet batteries at intervals along the cable route, but because of the absence of power lines in certain localities, this plan was discarded. In the plan finally adopted 130 volt telegraph batteries or 130 volt motor generators at the repeater stations were used to supply current to the cable sheath by means of pairs in the cable, as shown in figure 1. Four number 22 and 8 number 19 American wire gauge conductors were used in such combinations that the current to each point was of the order of 0.5 to 0.9 ampere. Connections were made to the cable sheath at 4 points in each direction from each intermediate repeater station and at 3 points near the Kansas City end. The distance between the points of contact varied from 3.12 to 9.08 miles, with an average of about 5.5 miles. In addition, about 0.5 ampere was applied to the cable sheath at each intermediate repeater station. In order not to corrode the regular central office ground at the repeater stations by the current used for counter potentials, special long-life grounds were installed at most of these points.

The results of this mitigation system have been very gratifying. The cable in each manhole from St. Louis to Kansas City is now negative to earth. The minimum potentials are slightly less than 0.1 volt and the maximums at points of application of the counter potentials range up to 1 volt. The system has been in operation for nearly 3 years with no evidence of additional corrosion on the cable, and all evidence indicates that the old pitting has definitely stopped. The potentials of the cable sheath to earth for a typical repeater section before and after completion of the preventive system are shown in figure 2. A representative picture of the pitting effects found on some 30 spare lead sleeves previous to the application of the counter potentials is given in figure 3.

The total direct current required to maintain the 225 miles of cable negative to earth is only 24 amperes, which means an average current density of about 30 microamperes per square foot of sheath. It is understood that this current value is very much smaller than is required for other installations of forced drainage.

Approximately 88 per cent of the total length of the cable, or 225 miles, is protected by the facilities described at an annual cost which is very low for insurance against the effects of corrosion with the inevitable replacement from time to time of sections of cable. Such replacements always are costly and are accompanied, especially in case of comparatively heavy cable fills, by adverse service reactions.

The outstanding features of this protective method are its stability and the very small amount of maintenance required. It is necessary only to check the current output occasionally in the connections to each point of application, which is done at the repeater stations by the regular attendants.

Wichita Electrolysis Mitigation System

The corrosion problem on the telephone cable plant at Wichita, Kan., has been very serious, dating back to the advent of the street railway system more

than 30 years ago. The condition became progressively worse as the underground plants of the various utilities grew. Finally, in 1931, an extensive mitigation system involving the coöperation of the Kansas Gas and Electric Company and the Western Union Telegraph Company was placed into effect. Some of the important features of the problem will be reviewed.

Wichita has a single local exchange located in the business district which is about 0.25 square mile in

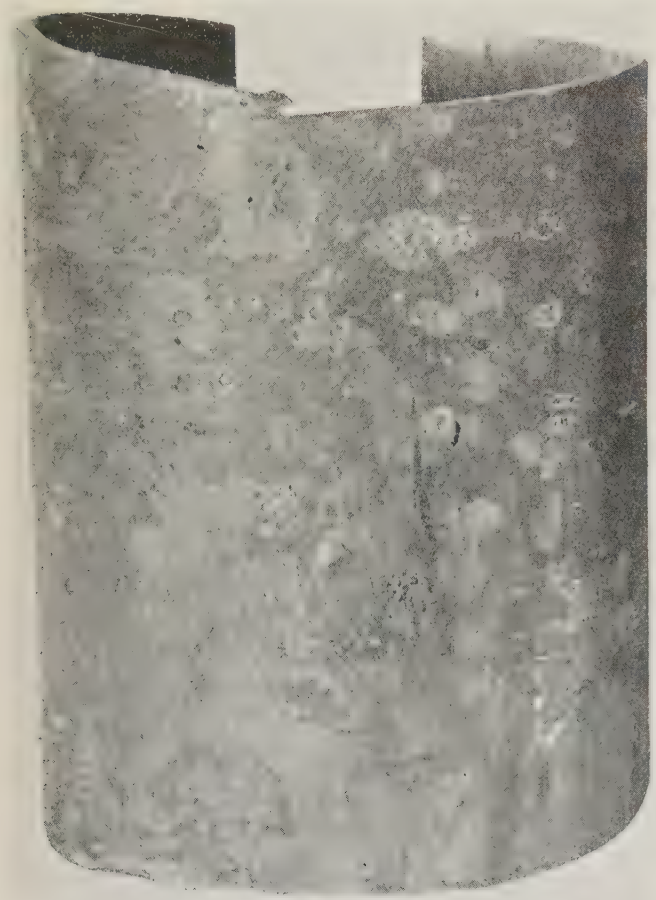

Fig. 3. Representative pitting effects found on spare lead sleeves previous to the application of the mitigative scheme

area, and underground is a grid of telephone, telegraph, and power cables, and gas, water, and steam pipe lines. The drainage of stray current from the district was complicated by the fact that the street railway's power was supplied from the electric company's generating plant, which was located nearly a mile from the telephone central office. The only stray current drainage from the district to the power plant was by way of the railway company's negative returns, the water company's mains, and the electric company's cable system. The problem was the more difficult of solution because only 35 per cent of the total railway load returned over the negative feeders as a result of the inadequacy of this system.

The telephone cable plant was negative to earth in all the outlying districts, but at about 80 manholes which include nearly the entire downtown district, conditions of from 0.1 to 0.5 volt positive to earth prevailed. Cable failures were rapid in this district, with an average of 7 or 8 per year. The telegraph company's cable plant also was generally positive to earth. The electric company's cable plant was consistently negative to earth from the drainage provided by feeder cables from the power plant.

The nature of the problem indicated that the best engineering solution would require coöperation of the cable-using companies in providing common drainage from the downtown network comprising their respective plants. It was evident that competitive drainage by all 3 companies would be decidedly uneconomical and would be almost impossible in providing a satisfactory solution. The mitigation system which was installed consisted, in general, of bonding the 3 cable plants together in 15 locations to form a uniform grid, and then increasing the conductivity from the downtown district to the power plant by means of about one mile of 1,000,000 circular mil drainage cable. Several shorter drainage wires also were used.

A great deal of stray current on the telephone plant was eliminated by isolating the cables at the central offices from the station grounds and placing insulating splices in all lateral building and block cables in the downtown district.

The electrolysis mitigation program which was completed in 1931 has resulted in a great improvement and a satisfactory condition for all utilities concerned. The telephone cable system now has about 15 manholes which are positive to earth. The potentials are under 0.1 volt and are constant throughout the 24 hour period, which indicates that the potential is caused by local conditions and not by stray current. No method has been found for eliminating the remaining positive condition without damaging other underground plants.

In view of the great amount of corrosion damage done by stray current over a period of many years, it was expected that cable failures would continue to occur for a number of years after the drainage system was installed. The results have been pleasing in that only 6 failures have occurred in the past 4 years, compared to the previous average of more than 6 per year. Duct electrodes have been installed in numerous places and are frequently inspected for any evidence of new corrosion.

The localized current problem has received considerable attention in recent years and according to present trends will become increasingly important with the extension of intercity toll cables and the abandonment of street railway systems. While the experience with the counter potential system of preventing corrosion is somewhat limited, the results obtained indicate that this will frequently be a very satisfactory method.

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Speed Transients of D-C Rolling Mill Motors

In its introductory part, this paper explains why the transient speed changes of d-c motors under suddenly applied loads may affect the quality of the product rolled on a continuous rolling mill. In a later section, the paper analyzes the behavior of such motors driving a tandem tube mill, and points out the difference between the transient and the steady-state speed-load characteristics; the former greatly affects the product, while the latter, or the conventional speed regulation, is of only minor importance. The paper outlines the course to follow in choosing the most suitable motors and gives a mathematical study of the transient speed-load changes.

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THE MODERN TENDENCY in rolling mill design and practice is toward tandem mills, which consist of several sets of rolls, or stands, arranged in line as shown in figure 1. The majority of stands are driven by separate motors as this greatly simplifies the mechanical layout. For this purpose, d-c motors, furnished with power from one or several generators, commonly are used. The speed relationship between the several stands is not fixed, but should be adjusted from time to time to suit the product rolled. By varying the generator voltage, the speed of the whole mill may be raised or lowered as a unit. The speed relationship between the stands may be altered by field control of the several motors.

Figure 1 shows, in elementary form, the layout of a typical tandem mill. The metal passes from stand to stand. Ordinarily the bar is sufficiently long to be in several, or even in all, stands at the same time. Hence, the speed of each successive stand should be raised in proportion to the reduction of the cross-section area so that the product of the speed times the area is constant. This expresses the obvious fact that the same amount of metal passes through each stand in any interval of time. Once established, the speed relationship between the stands should be maintained accurately because otherwise there will be created a tendency to stretch or loop the metal between stands.

If the rolled material is flexible, such as strips or the like, a small amount of looping is not objectionable. In fact, a loop often is desired, as it gives a positive indication that the metal is not being stretched.

When the product is of such a nature that its

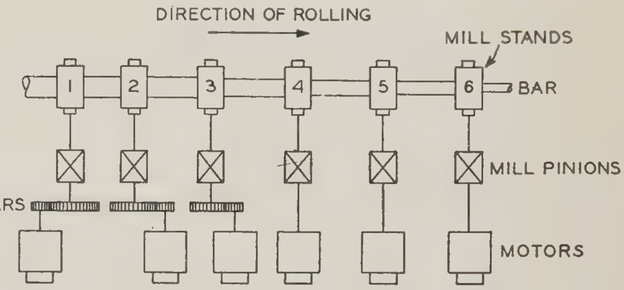

Fig. 1. Modern continuous, or tandem, rolling mill with individual drive for each stand

bending or looping is impossible, the problem of proper speed control becomes more involved. There is no visible indication as to whether the relative speeds are set rightly or not. Presumably the bar may be pulled apart or pushed together by the adjacent stands, but it is impossible to say, by looking at the mill, what is the magnitude of force being transmitted through the metal from stand to stand. The motor loads, indicated by ammeters, serve as crude guides. By strengthening the fields of those motors that pull the heavier loads, or by weakening the fields of motors that are underloaded, the operator, in a measure, may hold the mill under control. In hot rolling, any excessive pull or compression exerted on the bar may ruin the desired cross section. Hence, the operators of such a mill require means of fine control of motor speed; vernier field rheostats for each drive become indispensable, in order to control the loop or load properly.

If the tube or the bar that is rolled were infinitely long, the relative speeds of the several driving motors would be adjusted once, and then these

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speeds would not change. Only such factors as uneven heating of motor fields, or change of motor loads resulting from variations in metal temperature, would require an occasional adjustment of one or several vernier rheostats. In metal rolling practice, however, particularly in hot rolling, the bars are of limited length, since they have to be reheated in furnaces in a straight form before going through the mill. Thirty foot furnaces constitute a practical limit. Consequently, several separate bars go through the mill each minute, usually separated by intervals when there is no metal in the rolls. Thus the motor load changes several times a minute from friction load to its maximum value.

The speed of a d-c motor varies somewhat with changes of load. When the load is applied suddenly, the motor speed dips down (the "impact speed drop"), then recovers part or whole of this speed drop, and finally settles down at some steady state value, which may be either higher or (usually) lower than the running light speed.

The load is not applied simultaneously to the several motors driving a tandem mill. Hence, the periodic change from load to no-load condition upsets the proper speed relationship even if such were established with all stands full. The bar or the tube may be stretched or compressed temporarily between adjacent stands before the transient speed changes are over and the steady state load conditions reëstablished. This may result in permanent damage to the product rolled.

It was natural, therefore, for the mill operators to call for motors that would not change their speed appreciably with changes of load. A very close speed regulation has been specified on many occasions. This requirement, however, was based upon a misunderstanding of this term. The speed regulation of a motor, as defined in the Standards of the A.I.E.E., is the ratio of change of motor speed from full load to no load, to the full load speed. Both values are taken under steady state conditions; transient phenomena causing the impact speed drop are not taken into account in this definition. A motor may have a small speed regulation and yet a large impact speed drop, and therefore not be as suitable for use in tandem mills as another motor with a reduced impact speed drop and a larger speed regulation. In fact, it will be shown in the following analysis that in certain instances a too-close steady-state speed regulation does not give the best results.

In the summer and fall of 1933, the authors were called upon to analyze the performance of several d-c motors driving a tandem mill producing thin walled tubes. This mill will be used as an illustration in this paper; the method used, but not necessarily the conclusions reached, are applicable, of course, to any other tandem mill where the problems are similar.

Problem of Tandem Tube Mill

Typical behavior of motors driving the stands of tandem tube rolling mills is represented by the curves shown in figure 2. The test shows the dip in speed occurring when the tube strikes the rolls. If the motor of the preceding stand is running at normal speed, the length of tube between the 2 stands will undergo a compression stress until the motor of the second stand has recovered its speed. In common vernacular such "overfeeding" spoils a length of the tube, equivalent to the distance between stands, by causing it to "balloon." For this reason the percentage of scrap in tube rolling is frequently high.

Actually the length of tube between the 2 stands may undergo first a tension or stretching stress, and then the compression or "ballooning" stress. This will occur when the motor of the first stand has not

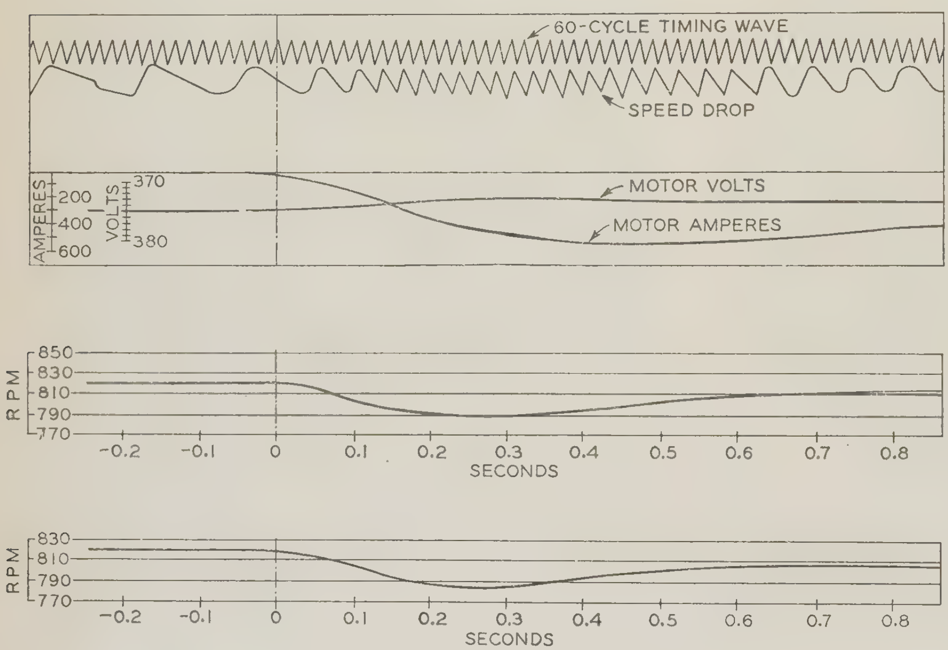


Fig. 2. Actual and calculated performance of a 325-horse power 815/1,630-rpm d-c motor driving one stand of a tandem tube mill

A—Test oscillogram taken during operation

B—Speed drop plotted from oscillogram

C—Speed drop calculated assuming constant flux

$\text{Rpm} = 820 - 17.9 - 29.4\epsilon^{-2.29t} \times \sin(7t - 0.63)$

yet recovered its normal speed before the tube strikes the rolls of the second stand. This is the usual situation as the stands are placed as close together as possible. The motor of the second stand, running at normal speed when the tube strikes the rolls, stretches the tube until a balance is reached between its falling speed and the recovering speed of the first motor, after which the ballooning stress occurs. It is the latter stress that is especially responsible for spoilage.

The curves shown in figure 2 were taken on a motor rated: 325 horse power, 815/1,630 rpm, 375 volts. The motor was operating at 375 volts, 820 rpm, running light and taking about 5 per cent of full load current. When the load suddenly was increased to 63 per cent of full load (to about 440 amperes) the speed dropped from 820 to 790 rpm in 0.25 second, and then recovered to approximately the original speed in about 1 second. Thus, the oscillograph record shows that the tested motor had an impact speed drop of approximately 3.7 per cent with load changing from 5 to 63 per cent of full load. If the load were changed from 5 to 100 per cent the impact speed drop would be slightly greater than 6 per cent. These tests were made on an existing mill where operation of the old motors was not satisfactory.

In the following part of the paper, the proper characteristics of motors designed to reduce the ballooning effect are described.

General Analysis

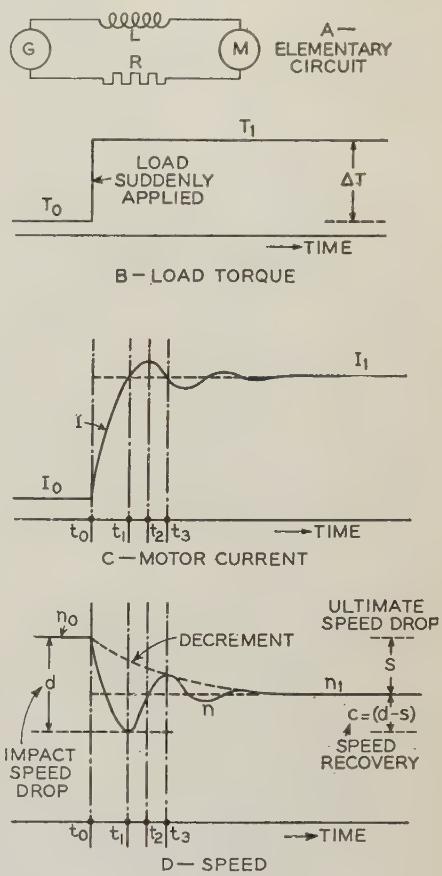
Figure 3 has been prepared to illustrate the elementary case, which is to be discussed. Assume that the motor is running light, developing a small torque just sufficient to overcome the mill friction and its own losses. The counter electromotive force of the motor is only slightly less than the impressed voltage, the difference between the 2 values being just enough to circulate the small current required to develop the small torque.

Now assume that at the instant t_0 the external torque suddenly has been increased. The running light current which has been flowing through the motor armature does not produce enough torque to balance the external torque; therefore, the motor will slow down and its counter electromotive force will be reduced. Ultimately the difference between the line voltage and the motor electromotive force will be such that enough current (I_1) will circulate through the motor to produce a torque to overcome the external load torque T_1. The ultimate motor speed will change from n_0 to n_1; the ratio of the ultimate change of motor speed (s) to n_1 is the value conventionally defined as the speed regulation. However, all these changes do not take place at once, but the motor goes through a certain period during which several transient phenomena occur. These phenomena should be studied most carefully because they are the ones that produce the undesirable effect on tube rolling processes.

In this discussion the magnetic flux of the motor will be assumed to remain constant during the described period. This is not strictly so, as will be explained further, but the effect of the flux changes will be described later and will be fully considered. The behavior of the motor after the load has been applied suddenly will be analyzed next.

As has been mentioned already, the motor torque at the initial instant is not sufficient to overcome the

Fig. 3. Diagrams illustrating fundamental behavior of d-c motors driving individual stands of a continuous mill



load torque; therefore, the motor will slow down, the rate of deceleration depending in the first place on the moment of inertia of the rotating parts. It is quite obvious that the larger the moment of inertia, the lower will be the rate of deceleration. It may be seen from the speed-time curve of figure 3 that at the instant t_1 the motor speed drop has reached its maximum. This maximum is the impact speed drop designated as d.

As the motor slows down, the difference between its counter electromotive force and the impressed voltage increases and, therefore, the current flowing through its armature also increases. However, this current does not rise as rapidly as the difference between the 2 voltages increases; this readily is explained by the fact that the motor armature possesses inductance just as any magnet or solenoid does. Therefore, rise of current always lags behind the rise of applied voltage that causes this current to flow.

At the instant t_1 the drop of motor speed (d) is sufficient to cause enough current to flow through the motor armature to balance the external torque, and therefore the deceleration of the motor ceases; however, the motor current still rises because the drop of speed (d) is greater than the ultimate drop (s) which causes current I_1 to flow under steady

state conditions. The current-time curve in figure 3 shows, therefore, that the current still rises from the instant t_1 to t_2. In other words, the motor develops during this time interval more torque than the external load, and this causes the motor to accelerate.

At the instant t_2 the motor will reach the speed n_1, which it will have under steady state conditions. However, the motor still develops more torque than the load requires and, therefore, the acceleration will proceed, bringing the motor speed to a value higher than n_1 (at the instant t_3).

These phenomena are quite similar to those of a conventional pendulum. The motor current and speed will oscillate about their ultimate values, this oscillation taking place during a very short interval. The energy of the oscillation finally is absorbed in resistive losses and in other losses, and the motor speed and current finally settle down to their steady state values.

It is quite evident from this description that the impact speed drop (d) is, generally speaking, larger than the conventional or steady state drop (s). Consider now what effect various factors, such as resistance, reactance, and mechanical inertia, have on the value of the impact speed drop.

Effect of Various Factors on Speed Drop

In order to study the effects of these various factors, figure 4 has been prepared. Diagram A of this figure is for a motor with arbitrarily selected values of resistance R, inductance L, and moment of inertia of the rotating parts. It is assumed further that the magnetic flux of the motor remains constant.

Resistance R is the resistance not only of the motor armature and its commutating field winding, but also includes the resistance of the generator armature and its commutating field winding, as well as the resistance of the connecting cables, etc. The same remark applies to the inductance L, which should include the inductances of all parts comprising the complete electric circuit. Furthermore, the moment of inertia includes not only the inertia of the motor armature, but also the inertia of other rotating parts driven by the motor.

Effect of Resistance. Assume now that the resistance R of the circuit has been reduced. Diagram B illustrates this case. With a smaller value of R, the motor speed drop will be less in order to cause the same current to flow through its armature windings. Therefore, the ultimate speed drop s and the impact speed drop d are reduced. (As long as the motor flux remains constant, the only thing that produces the speed regulation is the resistance of the circuit.) The reduction of the resistance R reduces the resistive losses in the circuit, and, therefore the oscillations do not die down as rapidly as shown on diagram A. Summing up, it may be concluded that the reduction of the resistance R is highly beneficial, particularly when the inductance and moment of inertia also are changed in the manner to be described.

Effect of Inductance. Diagram C illustrates the case when the inductance of the motor and of other parts of the circuit has been reduced, the resistance and moment of inertia remaining the same as in diagram A. The effect of reducing the inductance is twofold: In the first place, oscillations die down more rapidly (the time decrement is higher); secondly, the frequency of the oscillations is higher. The ultimate speed drop s is not affected by the change of inductance, but the impact speed drop is reduced because of the higher damping effect. On the whole, the reduction of the circuit inductance is very desirable.

Effect of Moment of Inertia. Diagram D shows the effect of increasing the moment of inertia of the system, other factors like resistance and inductance remaining the same as in diagram A. The higher is the inertia of the system, the lower becomes the frequency of oscillation. The ultimate speed drop s remains the same, but the impact speed drop d is reduced. The latter feature may be understood readily because the maximum dip of speed is likely to occur when the damping effect already has reduced the amplitude of the oscillations. Thus, it is highly desirable to increase the moment of inertia of the system to minimize the impact speed drop.

Combined Effect. It is evident from the previous discussion that in order to obtain the best results, as far as the value of the impact speed drop is concerned, it is necessary to reduce as far as possible the resistance and inductance of the circuit and to increase the inertia of the rotating parts.

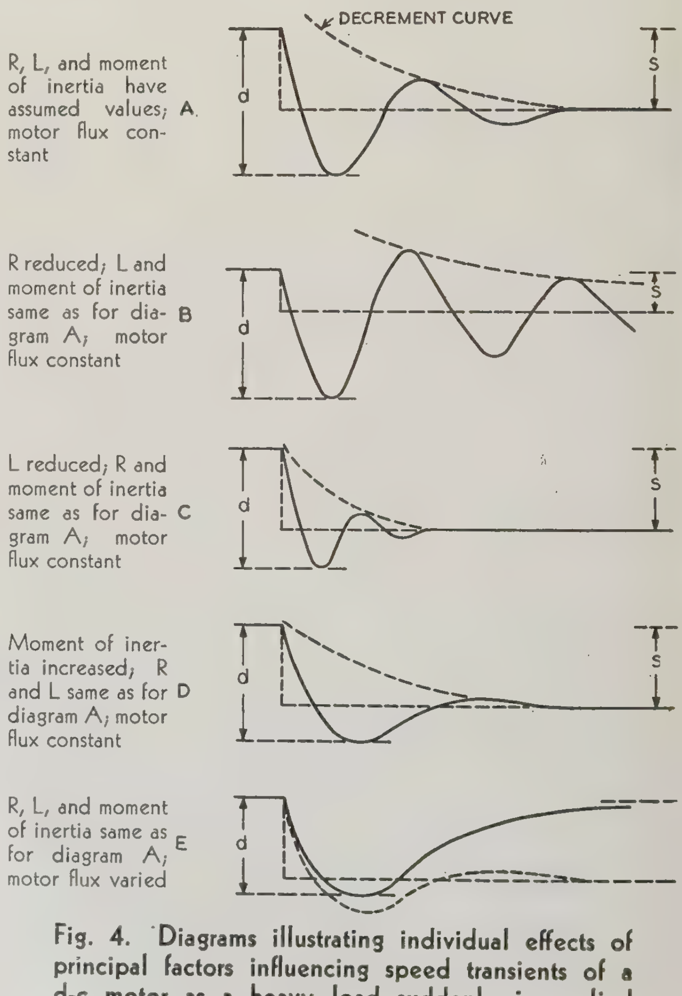


Fig. 4. Diagrams illustrating individual effects of principal factors influencing speed transients of a d-c motor as a heavy load suddenly is applied

Magnetic Flux. It has been assumed thus far that the magnetic flux of the motor remains constant when the load changes, and that the only thing that causes the motor to change its speed is the resistive (IR) drop in the system. Consider now what effect, if any, the change of the motor flux will have on the motor performance.

The current flowing through the motor armature produces the so-called "armature reaction" which tends to demagnetize the machine. Therefore, the motor speed tends to increase, counter-balancing in part the effect of the voltage drop in the resistance of the system. To put it differently, the armature reaction acts like a differentially wound series field.

The effect of the armature reaction is not instantaneous because anything affecting the main flux of the motor is delayed by the very appreciable time constant of the main field. Diagram E of figure 4 illustrates the effect of this armature reaction. The motor speed will not follow the dotted line (which corresponds to the speed-time line of the diagram D), but will follow the solid line which is somewhat higher than the dotted line. The ultimate speed drop s is obviously less than in the diagram D; the impact speed drop d also is reduced as compared with diagram D, which may appear to be rather desirable. Further analysis will show that this latter conclusion is not always correct.

Application of Results to Tandem Tube Mills

To illustrate the application of the theoretical results obtained to the practical case of the tandem tube mill drives, figure 5 has been prepared. On both diagrams A and B of this figure the solid line represents the speed-time curve of a motor driving *any mill stand*, while the dotted lines represent the speed-time curve of a motor driving the *following mill stand*. The speed-time curves of both motors are assumed to be identical. The curve of the following motor is merely shifted to the right by the time t_1 required for the tube to travel between these 2 stands.

The motor speeds, as plotted on these curves, do not represent the actual speeds, but the relative speeds of 2 motors. In other words, if these relative speeds are equal, then there is no stretching nor overfeeding between the 2 mill stands these motors are driving. On the other hand, if the motor, say number 10, is running relatively slower than motor 11, there is a stretching of the tube between the stands; likewise, when motor 10 runs relatively faster than motor 11, stand 10 overfeeds stand 11, and there is "ballooning" between these stands.

It is assumed that of the 2 evils, stretching and ballooning, the former is the less objectionable, particularly when very thin walled tubes are rolled. Therefore, while it is desirable to reduce as far as possible both the stretching and the ballooning, it is assumed that the latter effect should be minimized to the largest possible extent. This may or may not be true for other products rolled. Diagram A of figure 5 illustrates the case when the 2 motors under consideration have a relatively small "speed

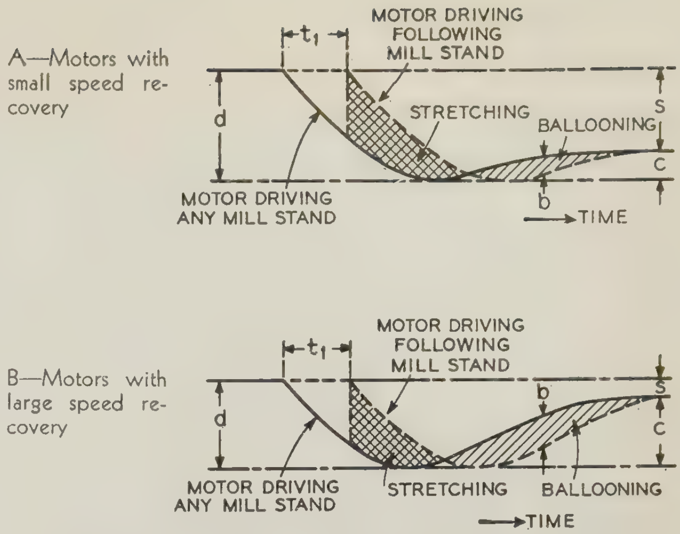


Fig. 5. Comparison of motors having large and small speed recovery

recovery." In other words, the motor flux remains more or less constant, the steady-state speed regulation is relatively large, but the speed recovery ($c = d - s$) is rather small.

The motors represented by diagram B have a rather large speed recovery. In other words, the conventional speed regulation has been reduced.

As long as the dotted speed-time curve is higher than the one drawn in solid lines, the tube between these 2 stands is being stretched. Therefore, this area is designated by the word "stretching." When the preceding motor is already on its way to recover while the following motor still is going through the early stages of the transient period, the solid line is higher than the dotted line, and therefore the ballooning effect takes place. The amount of this ballooning may be said to be proportional to the area marked "ballooning." The value b represents the maximum difference between the instantaneous values of the relative speeds of the 2 adjacent stands, and therefore this value should be held to the minimum.

Now from this viewpoint diagram A of figure 5 will be compared with diagram B. The motors with good (large) speed recovery, as represented by diagram B, have a small speed regulation and even the impact speed drop d is less than of the motors with small speed recovery, diagram A. One would be likely to conclude that the motors represented in diagram B, are the more desirable ones of the 2 combinations; however, this is not true. In order to reduce the amount of ballooning to a minimum, it is desirable to have the speed-time curves as flat as possible after they have passed their minimum values; the flatter are these curves, the less is the "ballooning" area and the smaller is the speed differential b. Thus, even though the motor combination of diagram B may look better because its speed regulation and its impact speed drop are less, from the practical standpoint the motor combination of diagram A should be preferred.

The conclusions reached may be summed up as follows: The driving motors should be designed

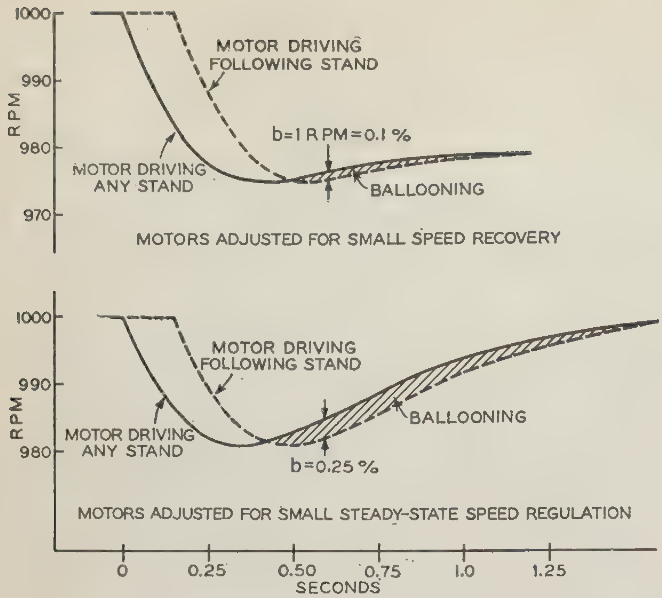


Fig. 6. Calculated performance of motors recommended for driving typical tube mill stands; motors rated 400 horse power, 1,000/1,500 rpm, 375 volts

Assumptions: Load changes suddenly from 5 to 100 per cent; tube travels 0.15 second from stand to stand. Allowance made for line drop and voltage regulation of generator

with as small a value of impact speed drop as possible. After this is done, their speed recovery should be held at the minimum, without too much attention being paid to the conventional or steady state speed regulation. In other words, after the motor speed is reduced, it is desirable to let it remain so rather than to recover while the tube rolling process goes on. In order to obtain these results, it may be desirable to equip the machines with a very light cumulative series field so proportioned as to offset in whole or in part the demagnetizing action of the armature.

Attempts have been made at various times to improve the steady state speed regulation of tandem mill drives, with the idea of improving the operating conditions. For instance, series exciters have been employed in order to control the degree of compounding of a d-c motor throughout its speed range and thus obtain a nearly flat speed-load curve. Mills are known where, at the insistence of the operators, special speed regulators have been provided, to hold the motor speed regulation (steady-state value, of course), within $^1/_4$ of 1 per cent. Quite obviously, this result, when obtained, did not have any effect on impact speed drop. In fact, a complete speed recovery would be detrimental to a mill like a tandem tube mill, as the foregoing analysis shows.

When the material rolled is flexible and can be looped between stands, the impact speed drop, creating a transient overfeeding, causes a small loop to form. After the motor speeds become stabilized under load, this loop ceases to grow and remains constant until the whole bar passes the mill. Here again, a flat steady-state speed-load characteristic may result in a larger loop than would have been obtained with a slightly drooping speed, everything else remaining constant.

In the appendix of the paper the analysis of the impact speed drop is given in more detail showing how the speed-time curve, when load is applied suddenly, may be calculated.

It is anticipated that the application of the results of this paper will result in improved performance of mills of the described type. New drives may be designed with such characteristics as have been pointed out. In some instances the operation of existing mills can be improved by equipping the motors with flywheels. This has been done with satisfactory results.

Tentative designs of motors for a proposed application have shown that the speed dip can be reduced to less than $^1/_3$ of the usual dip (see figure 6) without adding too greatly to the cost of the motors. This is accomplished by taking into consideration the effects of R, L, K_1, and M, as described in the appendix, and modifying the design to get desirable values for these factors. Of course, when the material can be looped between stands, as in strip mills, or when it can withstand considerable compression, motors of conventional design are well suited.

Finally, it is hoped that a clearer understanding of the transient speed-load changes will eliminate the numerous and expensive, but futile, attempts to correct the transient shortcomings of motors by improving their steady-state speed-load characteristics.

Appendix—Equations for the Motor Speed Characteristic

For the purpose of calculation, it is assumed that the torque is applied to the motor instantaneously, when the tube or bar being rolled strikes the rolls. The solution is obtained under the condition that the flux in the armature per pole, in both motor and generator, remains constant. Therefore, the speed disturbance is calculated without the demagnetizing or magnetizing effect of load, either for the motor or generator. However, this does not destroy the value of the solution as can be seen from succeeding paragraphs.

The demagnetizing or magnetizing action results from 4 causes: first, from the effect of magnetic saturation of the teeth and pole face due to the field distortion created by armature reaction; second, from the commutation, since the armature conductors short-circuited by the brushes, rotating in the commutating field and encircling the main axis of the machine, frequently give demagnetizing ampere turns as the load increases; third, from the direct effect of the commutating pole ampere turns if the brushes are set off neutral; and fourth, from the direct effect, either magnetizing or demagnetizing, of the series field. The first and second causes are inherent. The third and fourth are imposed and are adjustable within limits after the machine is built.

With the brushes set directly on neutral (equivalent to being directly under the center of the commutating pole) the third cause is eliminated. This is the normal position in commutating pole machines having a series field. Therefore, in the usual machine the change in the effective flux is entirely a change in the flux through the main poles, and is strongly resisted by the highly inductive main field winding. Actually the flux is substantially constant during the first portion of the speed dip. Thereafter, the calculated speed curve may be raised or lowered along its length in proportion to the change in flux. The total correction, if any, is known if the steady state speed regulation is known, or if it is assumed that adjustments will be made in test to obtain a specified steady state regulation. This total action takes place gradually over a relatively long period of time because of the slow decay of the induced field current. Furthermore, the correction easily is applied as the time constant governing the action is that of the field circuit, which is determined readily. With knowledge of these

facts, it is quite possible to calculate a highly accurate speed-time curve on the condition of constant flux. This method provides the simplest, quickest way of getting results.

Speed Equations

Consider a motor and generator with armatures connected together and with torque applied to the motor as shown in figure 3A. The current flowing in the circuit is:

$$i = \frac{E - e}{R + Lp}$$

where
E = voltage behind generator impedance
e = counter electromotive force of motor
R = total resistance of generator, motor, cables, etc.
L = lumped inductance of generator, motor, cables, etc.
p = d/dt

Inductance L is the total transient inductance of the armature circuit consisting of the total inductance of the armatures and commutating fields, minus twice the mutual inductance between those fields and armatures, plus the inductance of the cables. This is substantially a constant except on heavy overloads. The transient inductance of the series field is negligible. The total inductance, L, is only slightly less than the steady state inductance (flux linkages per ampere of sustained current) because the effect of the solid iron of the frame is to damp only a portion of the flux. It has been found that the steady state inductance may be calculated roughly by taking the unit resistance of the machine (equal to rated volts divided by rated amperes, or rated volts squared divided by rated watts) and dividing this by the rated angular velocity $(\pi Pn)/60$ as though it were reactance (P is the number of poles and n is the speed in revolutions per minute). The steady state inductance is 0.6 of the resulting value for uncompensated machines and 0.25 for compensated machines. Such approximate estimates have given remarkably close checks in 11 cases for which elaborate calculations have been made.

The electrical torque of the motor with constant flux is the product of a constant times the current. Therefore, this torque may be expressed by:

$$Ki = \frac{K_0 - K_1 n}{R + Lp} \tag{1}$$

where

$$K = \frac{P\phi Z 10^{-8}}{2\pi a}$$

$$K_0 = KE = \frac{P\phi Z\ 10^{-8}}{2\pi a}$$

$$K_1 = KK_2 = \frac{P\phi Z}{2\pi a 10^8} \cdot \frac{P\phi Z}{60 a 10^8} = \frac{(P\phi Z)^2}{120\pi (a10^8)^2} = \frac{30}{\pi}\frac{e^2}{n^2}$$

n = speed in revolutions per minute
P = number of poles
a = number of armature paths
Z = number of armature conductors
ϕ = flux per pole (maxwells)

All of the foregoing coefficients are for the motor.

The electrical torque must balance the total mechanical torque consisting of: the suddenly applied torque ΔT; the initial torque T_0 (including the friction of bearings, brushes, windage, etc.); and the inertia torque Mpn where M is an inertia constant of the motor armature and is equal to $(2\pi/60)(WR^2/g)$ in which W is the weight of the armature in pounds, R its radius of gyration in feet, and g the acceleration due to gravity.

$$Ki = (\Delta T) + T_0 + Mpn \tag{2}$$

Substituting equation 1 gives:

$$K_0 - K_1 n = (R + pL)(\Delta T + T_0 + Mpn)$$

and expanding:

$$\left(p^2 + \frac{R}{L}p + \frac{K_1}{LM}\right) n = \frac{K_0 - RT_0}{LM} - \frac{(R + Lp)}{LM}(\Delta T)\mathbf{1} \tag{3}$$

where **1** is Heaviside's unit function.

The solution of this equation by the expansion theorem is:

$$n = \frac{K_0 - RT_0 - R(\Delta T)}{K_1} + \frac{(\Delta T)\epsilon^{-\frac{Rt}{2L}}}{2K_1}\left((R+\beta)\epsilon^{\alpha t} + (R-\beta)\epsilon^{-\alpha t}\right) \tag{4}$$

where

$$\beta = \frac{R^2 M - 2LK_1}{2LM} \qquad \alpha = \sqrt{\frac{R^2}{4L^2} - \frac{K_1}{LM}}$$

For the oscillatory case let $\omega = \sqrt{\frac{K_1}{LM} - \frac{R^2}{4L^2}}$; then $\alpha = j\omega$

By this substitution:

$$n = \frac{K_0 - R(\Delta T + T_0)}{K_1} - \frac{(\Delta T)\epsilon^{-\frac{Rt}{2L}}}{\omega M}\sin\left(\omega t - \sin^{-1}\frac{R\omega M}{K_1}\right) \tag{5}$$

In the ordinary case the disturbance is a harmonic oscillation of the frequency $\omega/(2\pi)$ and amplitude $(\Delta T)/(\omega M)$. The axis of the oscillation is the final steady state speed at constant flux.

If n_0 is the initial speed and the torque is in foot pounds,

$$n = n_0 - \frac{1.36R(\Delta T)}{K_1} - \frac{1.36(\Delta I)\epsilon^{\frac{-Rt}{2L}}}{\omega M}\sin\left(\omega t - \sin^{-1}\frac{R\omega M}{K_1}\right) \tag{6}$$

Influence of R, L, and M

The influence of factors R, L, and M may be interpreted readily from the approximate equations following:
For values in the ordinary range

$$\omega = \sqrt{\frac{K_1}{LM} - \frac{R^2}{4L^2}} = \sqrt{\frac{K_1}{LM}} \text{ (very nearly)}$$

Substituting this approximate relation gives:

$$n = n_0 - \frac{1.36R(\Delta T)}{K_1} - 1.36\sqrt{\frac{L}{K_1 M}}(\Delta T)\epsilon^{\frac{-Rt}{2L}}\sin\left(\sqrt{\frac{K_1 t}{LM}} - \sin^{-1} R\sqrt{\frac{M}{LK_1}}\right) \tag{7}$$

This result shows that the speed fluctuation, starting from an initial speed n_0, is a damped harmonic oscillation about the speed $n_0 - 1.36R(\Delta T)/K_1$ as an axis. The amplitude of the oscillation is $1.36\sqrt{\frac{L}{K_1 M}}(\Delta T)$ and the damping exponent, or decrement factor, is $R/2L$.

These quite simple results led to the conclusions made earlier in the paper regarding the effects of R, L, and M. The effects of all factors, R, L, M, and K_1, may be summed up as follows:

1. The amplitude of the speed oscillation is $1.36(\Delta T)\sqrt{L/(K_1 M)}$ and is, therefore, independent of R, proportional to $\sqrt{L}$, proportional to $\sqrt{1/M}$, and proportional to $\sqrt{1/K_1}$.
2. The offset of the axis of oscillation is $1.36\ R(\Delta T)/K_1$ and is proportional to R, independent of L, independent of M, and proportional to $1/K_1$.
3. The frequency of the oscillation is $\sqrt{K_1/(LM)}/(2\pi)$ and is independent of R, proportional to $\sqrt{1/L}$, proportional to $\sqrt{1/M}$, and proportional to $\sqrt{K_1}$.
4. The damping is $R/2L$ and is, therefore, proportional to R, proportional to $1/L$, and independent of M and K_1.

It is obvious that the least fluctuation of speed occurs when the values of R, L, K_1, and M are such that they result in: (1) small amplitude, (2) small offset, (3) low frequency, and (4) large damping.

The factor K_1 is fixed by the voltage and speed of the motor. On the face of the results, a large value of K_1 would be desirable indicating that high voltage and low speed should be chosen for the motor. However, K_1 is a design factor related to R and L in such a fashion that the 3 factors always move to exactly compensating values so long as the current density in the copper, the flux per pole, and the number of poles are not changed. Therefore, K_1 is not a basic value, and the best motor is one for which R and L are made as low as possible. It is beyond the scope of this paper to go into the details of the design except to note that considerable improvement can be obtained through the proper choice of speed, voltage, number of poles, and other design features. As expected,

the theory points to an oversized motor and large inertia, especially the latter. A separate flywheel is advantageous.

References

The following articles, with their accompanying discussions, give an interesting background:

1. SPEED REGULATION OF MAIN ROLL DRIVES, L. A. Umansky. *Proc.* Assn. of Iron and Steel Elec. Engrs., 1927, p. 103–15.

2. THE DRIVE OF TANDEM ROLLING MILLS, A. F. Kenyon. A.I.E.E. TRANS., v. 47, 1928, p. 764–70.

3. 76-INCH HOT STRIP MILL, INLAND STEEL CO. R. W. Davis. *Iron and Steel Engr.*, Dec. 1934, p. 486–94.

Definitions of Power and Related Quantities

Definitions of power, power factor, and related quantities in an a-c circuit have been prepared in an effort to provide definitions which will be generally acceptable. If such general acceptance is obtained, they will be published as a part of the revised report on "Definitions of Electrical Terms" which is being prepared by the Sectional Committee on Electrical Definitions. The authors were requested to prepare this paper to give to engineers an understanding of the principles which have guided the preparation of the proposed definitions and to provide opportunity for their discussion. The definitions cover the entire field of single-phase and polyphase circuits. The explanations start with simple circuits and lead to the more complex.

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THIS paper has been prepared to present the reasons which have influenced the selection of the names and definitions of a number of quantities which are related to the concept of power in an a-c circuit. The preparation of the definitions was undertaken as part of a program which has for its object the recording and clarifying of the present terminology in the electrical field. This program is being carried on by the Sectional Committee on Electrical Definitions under the sponsorship of the A.I.E.E. and under the rules of procedure of the American Standards Association. As part of this program, the present paper was prepared by the authors at the request of the Institute's committee on instruments and measurements.

In no part of the field of clarifying electrical terminology is there greater need of a logical set of definitions than in connecton with power. As the set of definitons which are accepted will soon be published as a part of the sectional committee's report on American standard "Definitions of Electrical Terms," a statement of the considerations which have led to the selection of this particular set is appropriate at this time in order that a wider discussion may lead to further improvements.

The definitions concerning power in single-phase and in balanced polyphase circuits with sinusoidal currents and potential differences have been universally recognized for many years. The extension of these definitions to the more complicated cases where the currents and potential differences are not sinusoidal and the circuits are unbalanced presents difficulties which were early recognized. To aid in solving these difficulties, the A.I.E.E. held, in 1920, a symposium on the subject. This symposium failed to clarify the situation, and 2 fundamentally inconsistent definitions of power factor have persisted in the A.I.E.E. standards for many years. The problem was again brought to the fore by the "Roumanian Questionnaire" of 1928, and much valuable discussion of it has been stimulated by the special subcommittee on reactive power of the A.I.E.E. standards committee.

A problem of this sort can never be settled by the fiat of any authority, but its solution must necessarily evolve with the growth of science. Because of the controversial nature of the subject, most of the definitions pertinent to it were omitted from the first report of the Sectional Committee on Electrical Definitions which was published in August 1932. So many comments on this omission were sent to the committee that it appeared that the proper evolution of the subject might be materially assisted by carefully naming and defining the principal concepts involved. Because of the fundamental nature of some of these quantities, the preparation of their definitions was referred to the subcommittee on fundamental and derived terms of the sectional committee, and in the autumn of 1933 the present authors were charged with the duty of preparing this group of definitions.

In preparing the definitions, advice and criticism were obtained from a large number of engineers. Before writing any definitions, correspondence was carried on with a number of persons who had given

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Publication approved by the director of the National Bureau of Standards of the U. S. Department of Commerce.

particular attention to this field. A set of definitions was then prepared and circulated to a rather large group and over 20 written criticisms were received from different individuals and groups. After all these suggestions had been carefully considered, those definitions concerning which there was a wide difference of opinion were revised and resubmitted to the same group for further criticism. The purpose of this paper is to bring out the reasons which have led to the selection of the definitions in their present form.

In the appendix are given those definitions which are essential for understanding this paper. In the complete report which the subcommittee on fundamental and derived terms has submitted to the sectional committee, the definitions are first stated in as concise English as is consistent with a definite and precise statement. Each quantitative definition is then repeated in mathematical symbols. The use of mathematical symbols should require no apology as it is the one method of expression concerning which there is no possible ambiguity. However, it has not seemed necessary to the authors to include the mathematical statements in the appendix of this paper.

The definitions of the report are stated in general terms assuming that in each case, unless otherwise stated, periodic (nonsinusoidal) currents and potential differences are present. The adaptation of the definitions to sinusoidal cases is readily accomplished by omitting the harmonic terms. This method of treatment has not met with universal approval. Some critics felt that additional definitions which would be applicable only to sinusoidal and to balanced conditions should also be included. This suggestion has not been followed because the increased space did not appear to be justified in view of the ease with which the simplified form can be derived from the more general. Other critics felt that the definitions for some of the more unusual cases were unnecessary. Although this criticism was given very careful consideration, the authors reached the conclusion that the formulation of a complete and logical set of definitions is more important than an attempt, on their part, to select only those quantities which, at the present time, have sufficient importance to justify defining.

Every definition necessarily is a statement that a particular word or small group of words is to be used as a name to designate the idea defined. The problem of choosing the names is a matter of fundamental importance and in many respects proved to be more difficult than that of formulating the precise definitions. After the authors' tentative choice of names had evolved some very vigorous criticism, a sort of preferential ballot was circulated, offering a number of alternative names for each of several of the disputed quantities. The results of this ballot (modified slightly as required to maintain consistency among the different quantities involved) are the names in the present edition. It is to be hoped that these names will find universal acceptance in order to strengthen the A. S. A. program of standardization.

In selecting names, extensive use has been made of qualifying adjectives to distinguish between quantities which belong to the same general class. It is expected that these adjectives will be omitted by writers when the context indicates sufficiently well the particular quantity that is under consideration. However, such an omission should be made only if there is no possibility of misunderstanding. Verboseness is preferable to indefiniteness.

I. Fundamental Concepts

There are several fundamental concepts which must be kept in mind in making definitions concerning electric power. The first is that power is the rate of flow of energy and hence that it is measured at a particular boundary through which the energy flows. It follows that before measuring power, the boundary at which the power is to be measured must be specified. The only method of specifying the boundary so that it is applicable to all kinds of electric circuits is to consider a closed surface which incloses a region into which, or from which, the flow of energy is to be measured. Within this region may be included a power house or a single generator; a factory or a single lamp therein; a bank of transformers or a single rectifier. In any case, the algebraic sum of all the currents entering and leaving the region is zero at every instant. To identify a region completely, it is sufficient to designate all the places where the circuit enters or leaves the region. For convenience, these places will generally lie along equipotential surfaces where the bounding surface cuts the conductors of the circuit and each such cross section is called "a point of entry of the circuit" or "a terminal of the circuit." Nearly all measurements of power and related quantities are made by connecting apparatus at such points of entry.

It will be noted that these statements specifically exclude consideration of the distinction between potential difference and electromotive force. To have introduced these distinctions would have greatly complicated the discussion.

It can be seen that when the circuit considered lies within a region so that the surface inclosing it cuts no conductors, the definitions do not apply directly. The power associated with such a closed circuit is, however, essentially indefinite unless the consideration is extended to cover not only the flow of electrical energy but also the transformations from or into other forms of energy. Usually it is possible to make assumptions which serve in effect to separate such a closed circuit into portions, to each of which the present definitions immediately become applicable.

II. Names for the Quantities Involved

Before giving definitions of power, it is necessary to decide the names to be used in designating the various quantities to be defined. In deciding on names, the most difficult question is to determine whether the name "power" shall be applied to all the quantities which have the dimensions of voltage

times current. This can be best illustrated by taking as examples 2 terms which are familiar to all engineers. The question that must be decided is whether "apparent power" and "reactive power" shall be used to designate certain quantities, or whether these quantities shall be designated as "voltamperes" and "reactive voltamperes." A preferential ballot indicated that engineers were nearly equally divided in their preference regarding these 2 pairs of terms. A number of letters have been received explaining why one or the other set of terms is not suitable. Very few have pointed out the advantages of the set of terms which they favor. Under these conditions, the authors have decided to use "apparent power" and "reactive power" for the reasons which follow.

The quantities "apparent power" and "reactive power" have the same physical dimensions as "power" and therefore can be used in the same equation as "instantaneous power" or "active power." In other branches of physics and engineering, this is often considered sufficient justification for continuing a generic name. Moreover, the present tendency of engineering usage appears to be away from "voltamperes" and toward "power." In recent years committees of the Institute have frequently used these expressions.

It is a general principle of nomenclature that it is not desirable to name a quantity by some particular unit which is used to measure that quantity. Hence, it is not desirable to use "voltamperes" as the name of a quantity. If the units are in any way to be connected with the name of the quantity, it should be called "voltamperage."

There has been considerable diversity of opinion concerning the adjectives to be used to designate the various types of power. Of the expressions concerning which there appeared to be enough difference in usage to warrant placing them on the ballot, only 2, "active power" and "distortion power," had substantial majorities. In 3 cases, "vector power," "fictitious power," and "nonreactive power," the vote was so close that the result was indeterminate, and final decision had to be made by the authors.

III. Power in Single-Phase Circuits When the Currents and Potential Differences Are Sinusoidal

While the definitions of the quantities relating to power in a single-phase circuit,* when the current and potential difference are sinusoidal, are well established, a consideration of the properties of these quantities is important before extending the definitions to nonsinusoidal wave forms and to polyphase circuits.

1. **Instantaneous Power.** The definition of instantaneous power follows directly from the definition of a potential difference and hence instantaneous power is equal to the instantaneous current times the instantaneous potential difference. The algebraic sign of instantaneous power is determined by the signs of the current and potential difference at that instant, with the result that instantaneous power is in most cases negative during a small part of each cycle. If both current and potential difference are sinusoidal, the instantaneous power can be represented as a constant plus a sinusoidal function of the time which has double the frequency of the current. In a single-phase circuit, the potential difference is usually measured from one conductor which is taken as having zero potential. However, that is not necessarily the case, since, if any other point is chosen, the increase in the instantaneous power attributed to one conductor is exactly offset by the decrease in that attributed to the other conductor. Hence, the instantaneous power has the following properties:

a. It is independent of the choice of the point which is taken as the origin from which the potentials of the points of entry of the circuit are measured.

b. The total quantity for a region, measured at its points of entry, is equal to the algebraic sum of the contributions of the parts into which the region may be divided, the measurement for each part being made at its respective points of entry.

2. **Active Power.** Active power is the time average of the values of the instantaneous power, the average being taken over a complete cycle of the fundamental frequency of the alternating current. Since it is simply a time average of the instantaneous power, it has the same 2 properties listed under instantaneous power.

3. **Apparent Power.** In a single-phase circuit, the apparent power at the points of entry is the product of the effective value of the current and the effective value of the potential difference between the 2 conductors which carry the current. Apparent power, as defined above, requires that one conductor be taken as the origin from which to measure the potential of the other conductor. The conception of apparent power can be so extended that it will have property *a* listed above; *viz.*, the potentials may be measured from any point as origin, provided apparent power is treated as a complex quantity or vector, the rectangular components of which are active power and reactive power. The total apparent power is then obtained by the vector addition of the apparent powers for the 2 conductors. It is then evident that apparent power does not have property *b* listed above, since this property involves an algebraic addition. However, it does have the following analogous property:

c. The total apparent power (vector power) for a region is equal to the *vector* sum of the contributions of the parts into which the region may be divided.

Apparent power also has the following properties:

d. Apparent power is numerically equal to the maximum active power that can exist at given points of entry with the given effective value of the sinusoidal current and potential difference and hence is directly related to the size of the required equipment and to the generating and transmitting losses.

e. Apparent power multiplied by the cosine of the angular phase difference between the sinusoidal current and potential difference is equal to the active power.

f. Apparent power is proportional to the amplitude of the cyclic fluctuations in the instantaneous power when the currents and

* The term "single-phase circuit" is used throughout this paper with the limited meaning of a 2-wire single-phase circuit.

potential differences are sinusoidal and hence indicates the tendency to produce vibrations.

4. Reactive Power. Reactive power in a single-phase circuit with sinusoidal current and potential difference is the product obtained by multiplying the apparent power by the sine of the angular phase difference between the current and potential difference. It may be treated as a vector which is always in quadrature with active power, or as the absolute value of this vector. From the above mathematical statement, it follows that reactive power in a sinusoidal, single-phase circuit has the following physical properties:

In this and the following diagrams, the reactive power has been drawn positive, indicating that the current leads the potential difference as is the case in a capacitative circuit

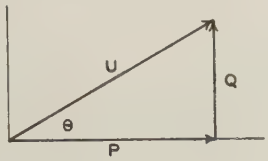


Fig. 1. Power diagram for a single-phase circuit under sinusoidal conditions

g. Reactive power is complementary to active power, since active power is equal to the apparent power multiplied by the cosine of an angle, whereas reactive power is equal to the apparent power multiplied by the sine of the same angle. From this, it follows that reactive power for sinusoidal conditions has 2 of the properties listed under instantaneous power and active power; *viz.* (*a*) it is independent of the point which is selected from which to measure the potentials of the 2 conductors; (*b*) it can be obtained by the algebraic summation of the reactive powers of the parts of the circuit.

h. Reactive power for sinusoidal conditions is proportional to the amplitude of the alternating component of the power resulting from the reactance of the circuit as distinguished from the pulsating component resulting from the resistance of the circuit.

i. Reactive power is equal to 4π times the frequency, times the amount by which the mean value of the stored electrostatic energy exceeds the mean value of the stored electromagnetic energy during a cycle.

The algebraic sign to be assigned to reactive power has presented a serious problem. In 1933, the U. S. national committee of the International Electrotechnical Commission sought for guidance concerning the conventional direction for plotting reactive power when treated as a vector. A careful survey of American opinion made by the special committee on reactive power of the A.I.E.E. showed that the negative (downward) convention for inductive reactive power (current lagging potential difference) was favored in about the ratio of 3 to 2. The committee on electrical and magnetic magnitudes and units of the International Electrotechnical Commission, meeting in Paris later in the year, formally adopted this convention. The authors therefore felt obliged to adopt the corresponding algebraic sign when reactive power is considered as a scalar quantity.

5. Geometric Power Diagram for Sinusoidal Conditions. The geometric power diagram in a single-phase circuit under sinusoidal conditions is shown in figure 1. It is a right triangle in which apparent power U is the hypotenuse, active power P and reactive power Q the 2 legs, and the angular phase difference θ the angle opposite Q. From this diagram the following additional relationship is immediately evident:

$$U^2 = P^2 + Q^2$$

The close analogy between this power diagram and the familiar admittance and impedance diagrams is evident.

IV. Extension of Power Concepts to Single-Phase Circuits With Nonsinusoidal Currents and Potential Differences

The commonly accepted method of dealing with problems involving nonsinusoidal quantities is to resolve each into its fundamental and harmonics by a Fourier analysis, and to treat each component separately. In extending power concepts, this method of analysis has been used as much as is feasible.

1. Instantaneous Power. In single-phase circuits in which the current and potential difference have harmonics, instantaneous power is necessarily defined in the same manner as for sinusoidal conditions. However, in this case, its variation is not a simple sine function of the time, so that the instantaneous power is given by an expression which includes the product of each harmonic term of the current by every harmonic of the potential difference.

2. Active Power. The averaging of the instantaneous power over a complete period of the fundamental component gives the active power for that period. This leads to a relatively simple expression, as most of the terms in the expression for instantaneous power disappear in the averaging process. In this way, it is shown that the active power under periodic conditions is equal to the algebraic sum of the active powers corresponding to the fundamental and to each harmonic. This extended definition to periodic conditions retains for active power the same properties as were given by the sinusoidal definition; *viz.* (*a*) it is independent of the point from which potentials are measured; (*b*) the total for an entire region is the algebraic sum of the parts into which the region may be divided.

3. Apparent Power. Apparent power also is defined in the same manner for periodic conditions as for sinusoidal conditions; *viz.*, it is the product of the effective (root-mean-square) current in one conductor by the effective potential difference between the 2 conductors. Apparent power as thus defined for periodic conditions has only 1 of the 3 special properties of apparent power as defined for sinusoidal conditions; *viz.*, that one given as *d* (in a previous paragraph) which states that the apparent power is the maximum possible active power for the given effective values of the current and potential difference. This property is generally considered as the most important of the 3. The relation between the apparent power and the active power depends not only upon the angular phase differences of the fundamentals and harmonics as indicated under *e* for sinusoidal conditions, but also upon their relative magnitudes. Also the extreme variations of the instantaneous power are not pro-

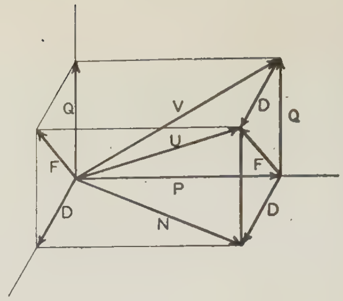
portional to the apparent power as given under f for sinusoidal conditions.

4. Reactive Power. Reactive power in a single-phase circuit with periodic current and potential difference is defined as the algebraic sum of the reactive powers corresponding to the fundamental and to each harmonic component. This definition retains the properties g, a, and b of the definition for sinusoidal conditions; *viz.*, that reactive power is complementary to active power, and like it, is independent of the point from which potentials are measured and the whole is the sum of the parts. It does not retain h and i, the close relation to reactance and to the storage of energy in the electromagnetic and electrostatic fields. Some engineers have suggested that the definition be modified by multiplying the reactive power of each harmonic component by its number for the purpose of retaining property i which relates reactive power with the rate of storage of energy in the electrostatic and magnetic fields. Such a multiplication destroys the parallelism with active power (property g). Other critics suggested limiting the concept of reactive power to sinusoidal conditions, except as it might be applied to the individual harmonics separately. If this were accepted, there would be, in a periodic circuit, no term complementary to active power, and hence the possibility of the further extension of power concepts would vanish. Neither of these proposals seemed to warrant changing a definition that has been in the A.I.E.E. standards (polyphase circuits) for many years.

5. Geometric Power Diagram for Periodic Conditions. With the definitions that have been chosen, the square of the apparent power is, in general, greater than the sum of the squares of the active power and reactive power when there are harmonics in the current and potential difference. Under these conditions the triangular diagram which is applicable to sinusoidal conditions must be modified. One method of doing this is to introduce a new quantity, distortion power, which is so defined that the square of the apparent power is equal to the sum of the squares of the active power, the reactive power, and the distortion power. Instead of representing these quantities in one plane, a more convenient diagram is obtained by a figure in 3 dimensions, as shown in figure 2. This diagram has the advantage that it gives a mental picture of the interrelations of all the power concepts that have been proposed in connection with single-phase circuits.

6. Distortion Power. This term was defined above in connection with the geometric power diagram. Its name appears to some extent in the literature and seems appropriate because the distortion power differs from zero only when the current or potential difference has harmonics (is distorted).

7. Fictitious Power. Fictitious power is defined as the square root of the difference of the squares of the apparent power and the active power. From the diagram, figure 2, it is seen that the square of the fictitious power is equal to the sum of the squares of the reactive power and distortion power. It is identical with the quantity which was defined as



This diagram is drawn to represent the vector addition, in 3 dimensions, of active power, P, reactive power, Q, and distortion power, D. The vector sum of P and Q is the vector power, V; the vector sum of Q and D is the fictitious power, F; the vector sum of P and D is the nonreactive power, N; while the vector sum of all 3 is the apparent power, U

Fig. 2. Power diagram for a single-phase circuit under periodic (nonsinusoidal) conditions

reactive power in the A.I.E.E. standards (single phase) in 1921. Some change in the name was required because the A.I.E.E. standards had 2 conflicting definitions for "reactive power."

8. Vector Power. Vector power is defined as the square root of the sum of the squares of the active power and reactive power. It has the property a above; *viz.*, it is independent of the origin from which potentials are measured; and also property c, *viz.*, the whole is the vector sum of the parts. In addition to forming a rational part of the power diagram for periodic conditions in single-phase circuits, it is particularly useful in polyphase circuits. The concept was formally defined for such circuits by the A.I.E.E. in 1920, the name "vector voltamperes" being applied to it at that time. It will be seen that if there are no harmonics, vector power in a single-phase circuit becomes identical with apparent power.

9. Nonreactive Power. Nonreactive power is the square root of the sum of the squares of the active power and distortion power. This term has been introduced to complete the naming of the edges of the power diagram. The name was chosen to indicate that it is the residue when reactive power is subtracted vectorially from apparent power.

V. Balanced Polyphase Circuit Under Sinusoidal Conditions

The extension of power concepts to a balanced polyphase circuit with sinusoidal currents and potential differences, both of which form symmetrical sets, follows directly from the single-phase definitions under sinusoidal conditions. Because of the symmetry, such a circuit may be considered as divided into a group of single-phase circuits, each having the same effective current and potential difference, with the same phase difference, as every other. The manner of separation into equal single-phase circuits is immaterial, but the customary method is to consider the single-phase circuits as the arms of a star network, with the currents those in the line conductors and the potential differences those from each line conductor to neutral. Each power quantity for the balanced polyphase circuit is defined as the sum of the corresponding quantities for the single-phase circuits. However, the instantaneous power in a balanced polyphase circuit under sinusoidal conditions does not change during a cycle as is the case in a single-phase circuit. All

the power concepts connected with a single-phase circuit under sinusoidal conditions, *viz.*, active power, apparent power, and reactive power, are thus extended to a balanced polyphase circuit under the same conditions. They have the same properties that they have in the single-phase circuits, except that, since there are no fluctuations in instantaneous power, apparent power cannot be correlated with such fluctuations.

VI. Balanced Polyphase Circuit Under Nonsinusoidal Conditions

The extension of power concepts to a balanced* polyphase circuit with harmonics in the currents and potential differences may be accomplished by considering the circuit either as separated into a group of single-phase circuits each of which has the same current and potential difference as every other or as divided into an assemblage of balanced sinusoidal polyphase circuits in which the frequencies of the currents and potential differences are those of the fundamental and the harmonics of the currents and potential differences of the balanced circuit. If the first method is employed, "active power," "reactive power," "apparent power," "distortion power," "vector power," "fictitious power," and "nonreactive power" are all obtained by multiplying the values for one single-phase circuit under periodic conditions by the number of circuits. The properties of the various quantities when summed in this way are the same as they are in a single-phase circuit. Hence, apparent power has the property *d* previously outlined; i. e., it is the maximum possible active power for the given effective currents and potential differences. However, the instantaneous power of the circuit is obtained by an algebraic summation of the instantaneous powers of the component single-phase circuits. It is, in general, not a constant but shows a cyclic variation with time.

If the second method is employed for each member of the assemblage of balanced polyphase circuits, values can be determined for the quantities "active power," "reactive power," and "apparent power," as is the case with any balanced polyphase circuit under sinusoidal conditions. Active power and reactive power of the circuit are obtained by the algebraic addition of the contributions of the successive members of the assemblage. The vector power of the circuit is obtained correspondingly by the vector addition of their vector powers each of which is identical with its apparent power because each component is sinusoidal. The arithmetic sum of the apparent powers of the successive members of the assemblage does not give the same value for the apparent power of the circuit as was obtained by the first method. Because the apparent power as defined by the first method is generally recognized as the apparent power of a balanced polyphase circuit, and has the important property *d* noted above, that definition has been preferred to one that might have been formulated from the second method.

* The term "balanced polyphase circuit" is here used to indicate a circuit in which all the potential differences of the polyphase set are symmetrical, and that the currents are also symmetrical but do not necessarily have the same wave form as the potential differences. See definition of a symmetrical set in the appendix.

VII. Unbalanced Polyphase Circuit Under Sinusoidal Conditions

The extension of power concepts to an unbalanced polyphase circuit with sinusoidal currents and potential differences, all of which have the same frequency, can be made either by separating the polyphase circuit into a group of single-phase circuits, in which the currents are those in the conductors at the points of entry and the potential differences are measured from a common point, or by resolving the unbalanced polyphase circuit into an assemblage of balanced polyphase circuits in which the characteristic angles of the symmetrical sets of currents and potential differences of the members of the sequence are integral multiples of a common angle.

The customary method of separating into single-phase circuits is to choose an origin from which to measure potentials and to consider that the single-phase component circuit corresponding to each point of entry carries the current in the corresponding conductor with a potential difference equal to that between the origin and the given point of entry. Since instantaneous power, active power, and reactive power are independent of the point chosen as an origin, their values are the same for every possible separation into single-phase circuits. Also, their properties are identical with those which they have in single-phase circuits and in balanced polyphase circuits.

It is to be noted, however, that although the insertion in the usual manner of a set of wattmeters at the terminals of an unbalanced polyphase circuit gives a theoretically correct measurement of the active power in the polyphase circuit, the corresponding method for measuring reactive power will not give a correct result if both the currents and the potential differences form unsymmetrical sets. A theoretically possible but impracticably complicated sequence network is required for a correct measurement of reactive power in this case.

There is no one quantity in an unbalanced polyphase circuit which possesses the properties of apparent power in a single-phase or a balanced polyphase circuit. To meet this situation, a number of different quantities have been suggested, each of which is in some respects analogous to apparent power, with the result that, in an unbalanced polyphase circuit, apparent power must be considered as a generic term. Four of these quantities which appear to have the greatest significance, practical or theoretical, have been formally defined as extensions of apparent power to unbalanced circuits. Each of these extensions postulates some particular manner of separating the polyphase circuit into component single-phase circuits, and each defines the total apparent power by a suitable combination of the apparent powers of the component circuits.

1. Arithmetic Apparent Power. Arithmetic apparent power in an unbalanced polyphase circuit is defined as the sum of the apparent powers obtained by multiplying the effective current in each line

conductor at the point of entry by the effective potential difference between it and the actual neutral, when one exists, or, if one does not exist, then an artificial neutral arbitrarily defined by the potential of the junction of a star of equal impedances connected to the line terminals.

Although this extension corresponds to the one which is commonly employed in extending the definition of apparent power from single-phase circuits to balanced polyphase circuits, yet in the unbalanced circuit, arithmetic apparent power, unfortunately, has none of the properties of apparent power in either of the simpler types of circuit. Because of this lack of definite properties, the A.I.E.E. did not, in 1920, include this definition in their standards. However, a number of engineers have urged its inclusion, possibly because it can be readily obtained from measurements with ammeters and voltmeters. The name has been chosen because it is the *arithmetic* sum of the contributions of the different component circuits.

2. Limiting Apparent Power. Limiting apparent power, in the case of an unbalanced circuit which is intended to be supplied with power from a symmetrical polyphase source, is equal to the maximum power which could exist at the points of entry of the circuit without loading any one of them more heavily than the actual load does at the most heavily loaded one. Like arithmetic apparent power, it is simple to measure; but unlike the former, its value is determined from a single current and a single potential difference.

3. Algebraic Apparent Power. Algebraic apparent power in an unbalanced polyphase circuit is so defined that it possesses property *d*, previously outlined, of single-phase and balanced polyphase circuits; *viz.*, it is equal to the maximum active power that can exist at the given points of entry with the given effective values of the currents in, and the potential differences between, the points of entry. This is the Lyon-Lienard concept of apparent power and requires that the common point of the group of component single-phase circuits be chosen in a particular manner. The determination of the common point for the purpose involves the various values of current as well as of potential difference. If the common point is located by a star of resistances, there may be required, in extreme cases, one or more arms having a negative resistance. When this is the case, the contributions from the corresponding component circuits must be considered negative, hence the name *algebraic* apparent power.

4. Vector Power. Vector power in an unbalanced polyphase circuit under sinusoidal conditions is defined as the square root of the sum of the squares of the active power and reactive power. As in the previous use of this term, it has properties *a* and *c*; *viz.*, it is independent of the point of measuring potentials and the whole is the vector sum of the parts.

It is to be noted that the distinction between vector power and apparent power arises from the unbalance of the circuit. In a balanced polyphase circuit, vector power, arithmetic apparent power,

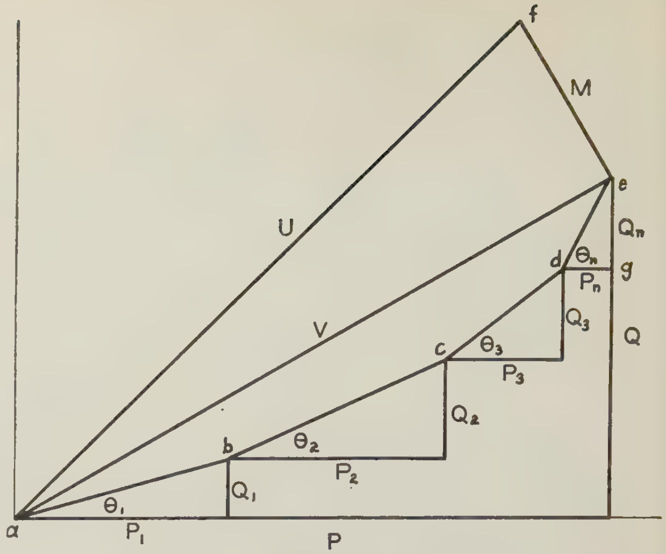


Fig. 3. Power diagram for an unbalanced 4-wire polyphase circuit under sinusoidal conditions

This diagram represents in one plane the vector addition of the contributions, corresponding to a particular origin from which potentials are measured, from each of the 4 points of entry. The vector, M, representing the mesh power, is drawn perpendicular to the vector power, V, and of such length that the vector sum of V and M has the magnitude of the apparent power, U

and algebraic apparent power all have the same value and are called apparent power in the same way as, in a single-phase circuit, vector power and apparent power become identical when there is no wave distortion and are similarly called apparent power. Another feature of vector power is its identity, under sinusoidal conditions, with algebraic apparent power in a circuit with 3 points of entry.

5. Mesh Power. Mesh power has been suggested (see reference 1 at end of paper) as a quantity to connect algebraic apparent power with vector power in an unbalanced polyphase circuit under sinusoidal conditions in the same manner that distortion power is used to connect these quantities in a single-phase circuit when harmonics are present. Hence, a definition of mesh power comes from the relationship that the square of the algebraic apparent power is equal to the sum of the squares of the active power, reactive power, and mesh power. A similar definition can be formulated to connect vector power with arithmetic apparent power, so that adjectives may be required to distinguish the 2 possible kinds of mesh power.

6. Geometric Power Diagram for a Sinusoidal Unbalanced Circuit. A geometric power diagram for an unbalanced 4-wire circuit under sinusoidal conditions is shown in figure 3, the length of the sides being numerically equal to the value of the corresponding power quantities. In this case, the diagram has been made in one plane, since there are no harmonics and hence no distortion power. The length *af* has been chosen equal to the algebraic apparent power U, and *fe* is drawn at right angles to *ae* so that M represents the mesh power. This diagram shows the vectorial nature of the sum-

mation which gives the straight line *ae* as the vector power of the entire circuit.

If the separation of the 4-wire circuit into single-phase component circuits has been made by measuring the potentials from the actual neutral, or, in its absence, an equal-arm artificial neutral, the triangle *deg* will reduce to a point. The arithmetic power is then equal to the arithmetic sum of the hypotenuses of the remaining 3 triangles; i. e., the length of the broken line *abcd*. This shows that arithmetic apparent power is greater than the vector power unless the angular phase differences of the component circuits are identical.

For each point which may be chosen as the origin from which to measure the potentials, there is a corresponding power diagram. If this point is determined by a resistance star having the properties required for measuring algebraic apparent power, then the length of the broken line *abcde* is the algebraic apparent power. However, in obtaining the length of the broken line, those parts of the line corresponding to those arms of the star in which the resistance has a negative value must be taken as negative. This broken line will be longer than *ad* except when all the phase angles are equal. With only 3 points of entry the phase angles of the separate circuits which determine the algebraic apparent power are necessarily equal, but this may not be the case with 4 or more points of entry. When the phase angles are not equal, mesh power must be introduced to account for the difference between the length of the broken line *abcde* and the straight line *ae*, in that diagram in which the potentials are measured from the point required for determining algebraic apparent power.

7. Symmetrical Components. The method of resolving an unbalanced polyphase circuit in which the currents and potential differences are sinusoidal into a group of balanced circuits, in each of which the currents and potential differences form symmetrical sets, furnishes an alternative procedure for treating power problems in such circuits. This method of separating an unbalanced polyphase circuit into a group of balanced polyphase circuits instead of into a group of unequal single-phase circuits avoids some of the difficulties which have been noted in the preceding paragraphs. When such a resolution is made, the various definitions of power as extended to a balanced polyphase circuit under sinusoidal conditions are directly applicable. The active power and reactive power of the separate balanced polyphase circuits can be added algebraically to obtain the total active power and reactive power respectively of the unbalanced circuit. The vector sum of the apparent powers of the symmetrical components is, for the unbalanced circuit, identical with the vector power as obtained by separating into a group of single-phase circuits.

VIII. Unbalanced Polyphase Circuit Under Nonsinusoidal Conditions

The extension of power concepts to the general case of an unbalanced polyphase circuit, with harmonics in the currents and potential differences, may be accomplished as in the preceding cases by considering the circuit as separated either into a group of single-phase circuits, in which the currents are those in the line conductors and the potential differences are those between a common point and the line conductors, or as divided into an assemblage of unbalanced sinusoidal polyphase circuits in which the frequencies are those of the fundamental and harmonics.

The method of separating into single-phase circuits permits the immediate application of the analysis of each circuit by the extension already given for a single-phase circuit under periodic conditions. There is no unique division of an unbalanced polyphase circuit into component single-phase circuits, since no possible separation will give a group of identical circuits. The method generally employed is the same as was outlined for an unbalanced sinusoidal circuit; *viz.*, choose a common point from which to measure potentials and consider the component circuits as characterized by the current in each conductor and by the potential difference from the point of entry of the conductor to the common point. As in the unbalanced sinusoidal case, the instantaneous power, the active power, and the reactive power of the entire circuit can be obtained by the algebraic summation of the corresponding quantities for the single-phase circuits as defined for a single-phase circuit under periodic conditions. Also, a vector summation of the vector power of the component circuits gives the vector power of the entire circuit. These 4 quantities have all the properties that they possessed in a single-phase circuit, so that they are independent of the point from which the potentials are measured, and are additive. All the other power quantities need to be separately considered. All excepting arithmetic, algebraic, and limiting apparent power can best be considered in connection with the geometric power diagram for this type of circuit.

1. Arithmetic and Limiting Apparent Power. Arithmetic and limiting apparent power are respectively defined in the same manner for a circuit under unbalanced periodic conditions as under unbalanced sinusoidal conditions. Since they depend only upon the effective values of currents and potential differences, a knowledge of the wave form is not required in the measurement of either. As in the unbalanced sinusoidal case, arithmetic apparent power has none of the properties associated with it in single-phase circuits.

2. Algebraic Apparent Power. Algebraic apparent power is also defined in the same manner for a circuit under periodic conditions as under sinusoidal conditions. This requires the selection of a particular point from which to measure potentials. With 3 points of entry, it may not be the same as vector power, as was the case with an unbalanced sinusoidal circuit. In other respects, the statements made for a sinusoidal unbalanced circuit are directly applicable.

3. Geometric Power Diagram of a Periodic Unbalanced Circuit. The geometric power diagram for an unbalanced, 3-wire circuit under periodic

conditions is shown in figure 4. In the diagram is shown the vector summation in space of the active powers, the reactive powers, and the distortion powers of the component circuits. If the potentials used in obtaining the quantities for this diagram were all measured from the neutral (either the real neutral or an artificial neutral obtained as indicated in the definition for arithmetic apparent power), the length of the broken line *abcd* is equal to the arithmetic apparent power. On the other hand, if the point from which the potentials are measured is determined by the star of resistances required by the definition of algebraic apparent power, the length of the broken line *abcd* is equal to the algebraic apparent power, unless the star of resistances contains one or more negative resistances, in which case an algebraic sum of the lengths of the lines *ab*, *bc*, etc., is required, the sign of each term depending upon the sign of the resistance. In either case, the vector power is not equal to the vector sum of the lines *ab*, *bc*, and *cd*, which is the line *ad*, but to the projection of *ad* on the *PQ* plane.

The algebraic sum of the active power and of the reactive power is the same for each of the power diagrams that can be constructed for a given set of conditions. Hence, the vector power of the unbalanced circuit is independent of the point from which potentials are measured. However, the sum of the distortion powers is not the same in the different diagrams. It follows that distortion power is not definite unless the particular point from which potentials are measured is specified. In any case, the broken line *abcd*, which represents apparent power, is equal to or larger than the straight line *ad* which represents the vector summation of active power, reactive power, and distortion power. Hence, another quantity, mesh power, is introduced which is equal to the line *df* drawn perpendicular to *ad* and of such length that the hypotenuse of the right triangle *adf* is equal to the apparent power.

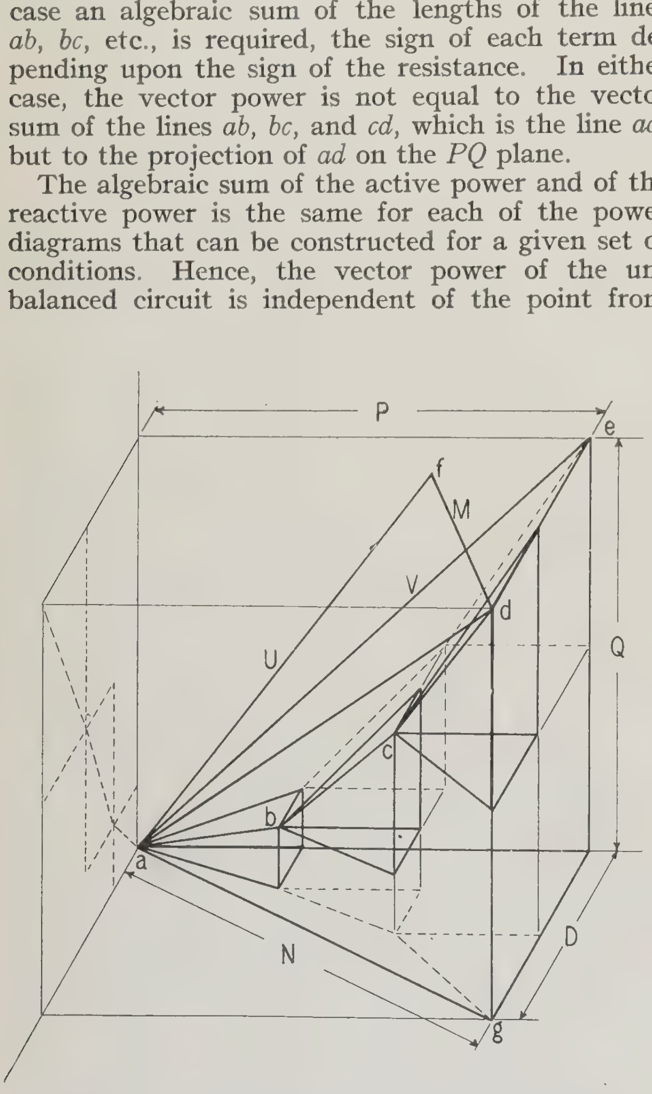


Fig. 4. Power diagram for an unbalanced 3-wire polyphase circuit under periodic conditions

This diagram represents, in 3 dimensions, the vector addition of the contributions, corresponding to a particular origin from which potentials are measured, from each of the 3 points of entry. The projections are shown on each of the 3 coordinate planes. The mesh power, M, is drawn perpendicular to the diagonal ad, and of such length that the hypotenuse of the resulting triangle equals the apparent power. For the origins which give arithmetic and algebraic apparent power, respectively, the corresponding adjectives should be applied to distortion power and mesh power

4. Distortion Power. Distortion power for any given division of an unbalanced periodic circuit into single-phase circuits is the sum of the distortion powers of the separate circuits. If the division is that required for obtaining arithmetic apparent power, the sum of the distortion powers is the arithmetic distortion power; if that required for algebraic apparent power, the sum is algebraic distortion power.

5. Mesh Power. Mesh power is defined from the relationship that the apparent power is equal to the square root of the sum of the squares of the total active power, the total reactive power, the total distortion power, and the mesh power. It is definite only when the point from which potentials are measured is specified. Hence, in specific cases, the terms "arithmetic mesh power" and "algebraic mesh power" may be employed.

6. Symmetrical Components. The second method of treating power concepts in unbalanced polyphase circuits under periodic conditions is to resolve the harmonic component sets of both the currents and the potential differences into symmetrical components. This method is carried out in 2 steps. First, the polyphase sets of the currents in the points of entry and the potential differences to any convenient origin are resolved into a series of harmonic components. Next, the resulting unsymmetrical sinusoidal sets for each frequency are separated into their symmetrical components. Such a resolution is unique, so that the value of each symmetrical component of each harmonic component is independent of the point from which potentials are measured. The total active power is obtained by the algebraic summation of the active powers of all the symmetrical components of every harmonic component. The total reactive power is similarly defined. The vector power is the vector sum of the vector powers of the component parts. It is interesting to note that the arithmetic sum of all the individual vector powers gives a definite quantity which might be called symmetrical apparent power. However, this is not directly related to arithmetic apparent power, algebraic apparent power, or limiting apparent power.

IX. Circuits in Which the Effective Values of the Currents and Potential Differences Vary With Time

An extension of power concepts to circuits in which the effective values of the currents and potential

differences vary with the time is theoretically possible by literally applying the preceding definitions to each individual cycle separately, and suitably combining the results. In only a few cases is such an analysis useful. Only 2 cases will be considered.

The first case arises in connection with the sale of electrical energy because the charges are sometimes made to depend upon the average values of power quantities during a "demand" interval. Active power and reactive power, being scalar quantities, can be averaged by adding algebraically the respective values for each cycle and dividing by the number of cycles, or by some equivalent process. Vector power, however, is logically averaged by taking the vector sum of the values for each cycle and dividing by the number of cycles. The numerical value obtained by this vector averaging is equal to the square root of the sum of the squares of the average active power and the average reactive power. The average values of other power quantities do not appear to be required.

The second case arises in circuits in which there is persistent "hunting" or in which the load varies periodically with a period much longer than that of the alternating current. The average value of the active power is obtained by averaging over a period of the hunting or of the periodic load. The extension of the preceding definitions of other power quantities to this case is too specialized for standardization at the present time.

X. Power Factor

Power factor is a term which arose in connection with single-phase circuits to designate the numerical factor by which the value of apparent power is multiplied to give the value of active power. This is a definite factor in all single-phase and balanced polyphase circuits. Also, in these circuits, apparent power is identical with vector power. However, in the extension to unbalanced polyphase circuits, power factor becomes a generic term, requiring adjectives to distinguish the different relationships that may be required. Hence, vector power factor, arithmetic apparent power factor, algebraic apparent power factor, and limiting apparent power factor are all numerical factors by which the values of the similarly designated power quantities must be multiplied to give the value of active power.

Appendix—Extracts From Proposed A.S.A. Definitions

Points of Entry of an Electric Circuit (A Set of Terminals). The points of entry (or exit) for delimiting an electric circuit where it enters or leaves a region are the group of surfaces, one cutting each of the conducting paths where the path enters or leaves the region, each of which is individually an equipotential surface and each of which is also a part of the single surface that constitutes the boundary of the region. It follows from this definition that the algebraic sum of the instantaneous currents through a complete set of points of entry is zero at every instant.

Instantaneous Power. Instantaneous power at given points of entry of an electric circuit is, at any instant, the rate at which electrical energy is then being transmitted by the circuit through the boundary of the region which corresponds to the given points of entry.

Instantaneous Power of a Single-Phase 2-Wire Circuit. The instantaneous power at the 2 points of entry of a single-phase 2-wire circuit is equal to the product obtained by multiplying the instantaneous current in one conductor by the instantaneous potential difference between the 2 points of entry. The value of instantaneous power is given in watts when the instantaneous current is in amperes and the instantaneous potential difference is in volts.

Active Power of a Single-Phase 2-Wire Circuit (Power) (Actual Power). Active power at the points of entry of a single-phase 2-wire circuit is the time average of the values of the instantaneous power when the average is taken over a cycle of the fundamental frequency of the alternating current. The value of active power is given in watts when the effective current is in amperes and the effective potential difference is in volts.

Reactive Power of a Single-Phase 2-Wire Circuit. Reactive power at the 2 points of entry of a single-phase 2-wire circuit is, for the special case of a sinusoidal current and a sinusoidal potential difference of the same frequency, equal to the product obtained by multiplying the effective value of the current by the effective value of the potential difference, and by the sine of the angular phase difference by which the current leads the potential difference; and is, for the more general case of a periodic current and a periodic potential difference of the same fundamental frequency, the algebraic sum of the reactive powers corresponding to the sinusoidal harmonic components. The value of reactive power is given in vars when the effective current is in amperes and the effective potential difference is in volts.

Vector Power of a Single-Phase 2-Wire Circuit (Combined Power) (Vector Voltamperes). Vector power is equal to the square root of the sum of the squares of the active power and the reactive power. Vector power is generally treated as a vector of which the components are 2 mutually perpendicular vectors that have the magnitudes of active power and of reactive power. It follows that the total vector power is the vector sum of the vector powers of the harmonic components. The unit of vector power is the vector voltampere.

Apparent Power of a Single-Phase 2-Wire Circuit. Apparent power at the 2 points of entry of a single-phase 2-wire circuit is equal to the product of the effective current in one conductor multiplied by the effective potential difference between the 2 points of entry. The unit of apparent power is the voltampere.

Distortion Power of a Single-Phase 2-Wire Circuit. Distortion power is equal to the square root of the difference of the squares of the apparent power and the vector power. The unit of distortion power is the distortion voltampere.

Fictitious Power of a Single-Phase 2-Wire Circuit. Fictitious power is equal to the square root of the difference of the squares of the apparent power and the active power. The unit of fictitious power is the fictitious voltampere.

Nonreactive Power of a Single-Phase 2-Wire Circuit. Nonreactive power is equal to the square root of the difference of the squares of the apparent power and the reactive power. The unit of nonreactive power is the nonreactive voltampere.

Symmetrical Polyphase Set of Potential Differences. A symmetrical polyphase set of potential differences is a set in which each potential difference has the same effective value and the same wave form as each other potential difference and in which the individual potential differences form a closed sequence such that successive members differ in phase by equal amounts.

Characteristic Angular Phase Difference. The characteristic angular phase difference of a symmetrical polyphase set of potential differences or currents is the angular phase difference between adjacent members of the sequence.

Instantaneous Power of a Polyphase Circuit. The instantaneous power at the points of entry of a polyphase circuit is equal to the sum of the products obtained by multiplying the instantaneous current at each point of entry by the potential difference between that point of entry and some arbitrarily selected origin from which all the potential differences are measured (which may be the neutral point of entry). The value of the instantaneous power is given in watts when the currents are in amperes and the potential differences are in volts.

Active Power of a Polyphase Circuit (Power) (Actual Power). The active power at the points of entry of a polyphase circuit is the time average of the values of the instantaneous power at the points of entry, the average being taken over a complete cycle of the fundamental frequency of the alternating current. The value of active power is given in watts when the effective currents are in amperes and the effective potential differences are in volts.

Reactive Power of a Polyphase Circuit. The reactive power at the points of entry of a polyphase circuit is equal to the sum of the products obtained by multiplying the effective value of each harmonic component of the current through each of the points of entry, by the effective value of the corresponding harmonic component of the potential difference between the point of entry and an arbitrarily-selected origin (which may be the neutral terminal) and by the sine of the angular phase difference by which that harmonic component of current leads the corresponding harmonic component of the potential difference. The value of reactive power is given in vars when the effective currents are in amperes and the effective potential differences are in volts.

Vector Power of a Polyphase Circuit (Combined Power) (Vector Voltamperes). Vector power at the points of entry of a polyphase circuit is equal to the square root of the sum of the squares of the active power and the reactive power.

Average Vector Power. The average vector power at the points of entry of any electrical circuit, averaged over a time interval which contains a large number of periods of the alternating current, is equal to the square root of the sum of the squares of the average active power during the interval and the average reactive power during the same interval.

Arithmetic Apparent Power of a Polyphase Circuit. The arithmetic apparent power at the points of entry of a polyphase circuit, is equal to the arithmetic sum of the products obtained by multiplying the effective current at each point of entry by the effective potential difference between that point of entry and the neutral point of entry or, if one does not exist, an artificial neutral, the potential of which is established by joining it to each of the line points of entry by a set of equal resistances. The unit of arithmetic apparent power is the voltampere.

Algebraic Apparent Power of a Polyphase Circuit. The algebraic apparent power at the points of entry of a polyphase circuit is the algebraic sum of the products obtained by multiplying the effective current at each point of entry by the effective potential difference between that point of entry and an artificial neutral, the potential of which is established by joining it to each point of entry by a resistance that has a value (positive or negative) such that the ratio of the effective current in a resistance to the current in the point of entry to which it is connected, is the same for each of the resistances. The unit of algebraic apparent power is the voltampere.

Limiting Apparent Power of a Polyphase Circuit. Limiting apparent power of a polyphase circuit at the points of entry at which it is intended that the currents and potential differences shall form symmetrical sets, is equal to the result obtained by multiplying the largest effective value of current in any line conductor, by the largest effective value of potential difference between any 2 adjacent line conductors, and by the number of line conductors, and dividing this product by twice the sine of $^1/_2$ of the characteristic angular phase difference of the symmetrical set of potential differences. The unit of limiting apparent power is the voltampere.

Distortion Power of a Polyphase Circuit. Distortion power at the points of entry of a polyphase circuit is equal to the sum of the distortion powers of the group of single-phase circuits into which the polyphase circuit may be considered to be divided. A convenient method of division is to choose an origin from which to measure the potentials of the points of entry, and to consider the single-phase circuit corresponding to each point of entry as having the current in the conductor at the points of entry and the potential difference between the point of entry and the origin. The value of distortion power depends on the choice of origin as well as on the circuit. The unit of distortion power is the distortion voltampere.

Mesh Power of a Polyphase Circuit. Mesh power at the points of entry of a polyphase circuit is equal to the square root of the result obtained by subtracting from the square of the apparent power, the sum of the squares of the vector power and the distortion power; the same origin being chosen for measuring potentials in determining distortion power as in determining apparent power. It follows that mesh power must be designated as arithmetic or algebraic corresponding to arithmetic or algebraic apparent power. The unit of mesh power is the mesh voltampere.

Fictitious Power of a Polyphase Circuit. Fictitious power at the points of entry of a polyphase circuit is the square root of the difference of the squares of the apparent power and the active power. It follows that fictitious power must be designated as arithmetic or algebraic corresponding to arithmetic or algebraic apparent power. The unit of fictitious power is the fictitious voltampere.

Power Factor. Power factor is the ratio of active power to apparent power. It follows that the power factor of a polyphase circuit must be designated as arithmetic or algebraic to indicate whether arithmetic or algebraic apparent power is used in the denominator.

Vector Power Factor. Vector power factor is the ratio of the active power to the vector power.

Reactive Factor. Reactive factor is the ratio of reactive power to apparent power. It follows that the reactive factor of a polyphase circuit must be designated as arithmetic or algebraic to indicate whether arithmetic or algebraic apparent power is used in the denominator.

Reference

1. Reactive and Fictitious Power, V. G. Smith. A.I.E.E. Trans., v. 52, 1933, p. 748–51.

Instantaneous Overcurrent Relays for Distance Relaying

Instantaneous isolation of faults on transmission and distribution lines is ever a problem of the relay engineer. The use of instantaneous overcurrent relays as applied to the system of the Oklahoma Gas and Electric Company is discussed in this paper. Relays of this type were applied in conjunction with already installed overcurrent time delay relays, giving a form of distance relay protection. Operating results have proved the scheme to be highly satisfactory. Economies realized in the better coördination between relays and fuses by using instantaneous relays also are discussed briefly.

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THE rapid isolation of faults on transmission and distribution lines today is more a problem of economics than a problem of relay design. High speed relays of various types, suitable for many applications, are available. A particular scheme of relay protection worked out for the system of the Oklahoma Gas and Electric Company, is described

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in this paper. This scheme consists essentially of the addition of an instantaneous overcurrent element which in most cases was mounted inside the case of the regular directional and nondirectional overcurrent time delay relays already in use. This scheme provides what is essentially distance relaying, and has greatly simplified problems of relay coordination. The time required for the isolation of faults has been greatly reduced and generally satisfactory operation has been secured at a comparatively low cost.

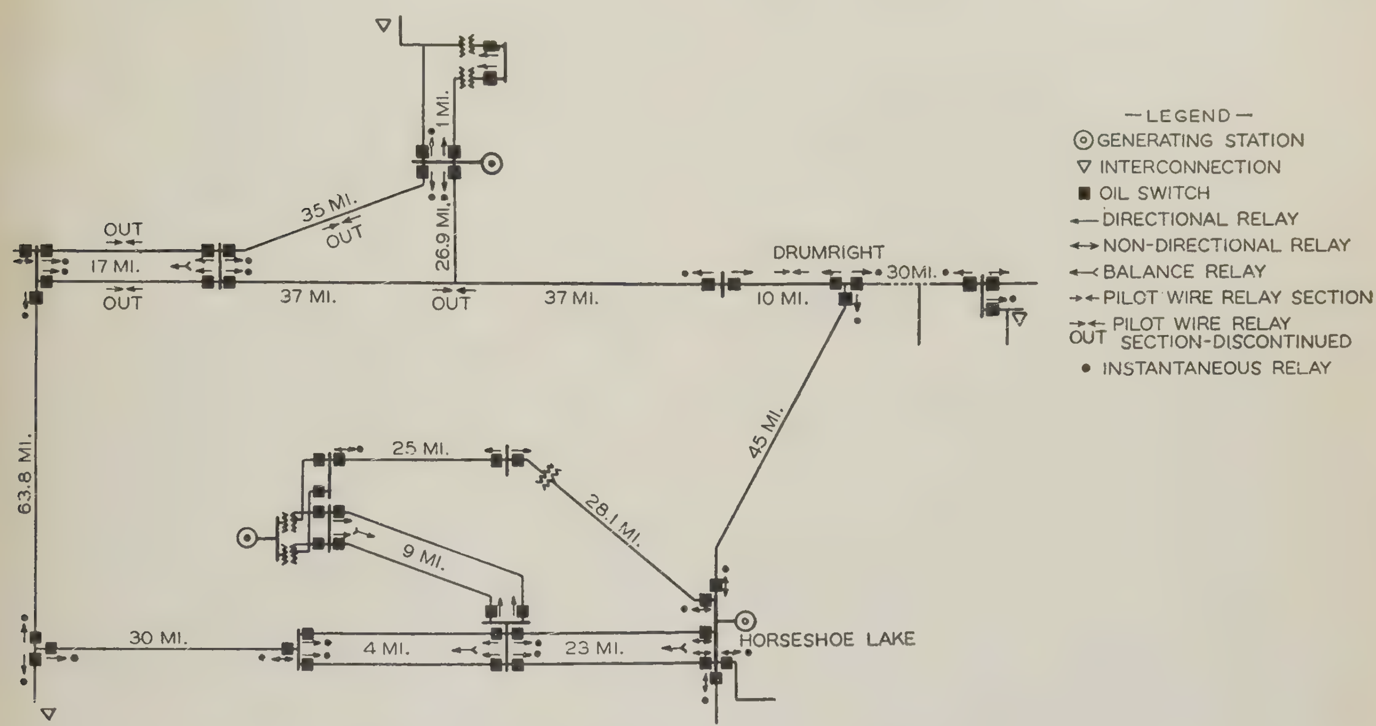

Fig. 1. A typical section of the system of the Oklahoma Gas and Electric Company

Transmission System Studied

Considerable study has been given the Oklahoma Gas and Electric Company's transmission system, particularly to relay sections where high overcurrent relay settings were threatening system stability. The time of relaying some faults has been as high as 2 seconds due to the necessity of backing up other relays on long transmission line loops and generating station tie lines having a large number of sectionalizing stations. Figure 1 is a sketch showing a portion of the 66 kv transmission system and indicating the type of relay equipment used. (This sketch also shows the application of instantaneous overcurrent relays as finally decided upon.) Long sections of line only were involved in this study, as all short lines are protected either by balanced relays or pilot wire relays.

The important problem of relaying lines at the generating plants received first attention as the relay settings at these points must necessarily be high. Comprehensive fault studies, which included 3-phase, line-to-line, and line-to-ground faults were made of each line with the different combinations of generating capacity, and the data plotted as "fault current per mile of line" curves. It was practical to make the great number of calculations necessary for this study by the use of a fixed resistor d-c symmetrical component calculating board,[1] on which the entire system is set up as a permanent unit arranged for readily obtaining fault current values for any condition of system operation. Figure 2 shows fault current values per mile of line from Horseshoe Lake generating station to the Drumright substation, a distance of 45 miles. These curves are plotted for the 3 combinations of generating capacity which obtain at this station.

Relay Schemes Considered

To obtain the objective of faster relaying it was necessary to consider high speed relays. A study of the fault current curves in figure 2 shows considerable variation in fault current values. For this condition a relay such as the ordinary type of distance relay that should clear a definite section of the line regardless of the value of fault current, would be desirable. Instantaneous overcurrent relays (relays without any time delay purposely introduced) alone could only relay a certain distance of the line if the generating capacity did not change appreciably. For any definite setting of these relays a certain section of the line could be relayed instantaneously, but if the generating capacity increased or decreased considerably, then they would either relay too much of the line with the possibility of overreaching into the adjacent relay section, or in the

1. For all numbered references, see list at end of paper.

latter case, relay a smaller portion of the line than desired.

Consideration of the various makes of distance relays indicated that while relays of the distance type would give instantaneous operation for a certain distance of the line only, the balance of the line must still be relayed by the time delay method to obtain back-up protection for the adjacent relay section. Relays of the distance type had desirable characteristics but immediately apparent was the relative high cost with the attendant cost of rearranging and rebuilding the present switchboard panels. In addition to this, a considerable amount of time of highly trained personnel for testing, maintenance, and setting of the relays would be required. This would probably result in an increase in the number of relay test men required. Some of the relays under consideration were a formidable array of springs, contacts, and levers, much too complicated for ready maintenance, which, undoubtedly, would entail considerable trouble and expense.

Application of instantaneous overcurrent relays in conjunction with present overcurrent time delay relays was finally decided upon, as the generating capacity under normal conditions did not vary greatly enough to prevent their application. By using this method, faults are isolated within $^1/_5$ second, which is comparable to any method of high speed relaying. This application was later justified by actual experience. The time of the regular overcurrent relays was materially reduced without decreasing the selectivity in any way, as these relays then become effective only for the last 15 per cent or 20 per cent of the line. This is possible because time delay selectivity is not necessary for faults near the sectionalizing circuit breakers and within the protective zone of the instantaneous relays.

Installation of the Device

In order to make the installation of the instantaneous relays as economical as possible, a unit was selected that could be mounted inside the case of the regular directional and non-directional overcurrent time delay relays. When used with directional relays the device is connected with its trip circuit in series with the directional contacts to insure correct operation in the right direction. Operation indicators were provided for each phase relay and the relay elements connected in such a manner that the operator would know immediately whether the time delay or instantaneous element had operated. By these means accurate records of relay operations are obtainable. A constant check of instantaneous operations is of particular importance as it is necessary to know whether the settings are correct for actual operating conditions.

Operating Results

From July 1933 to December 1934, the Horseshoe Lake-Drumright line tripped 22 times. The instantaneous relays operated 18 times, or 81.8 per cent of the relay operations. Selecting other lines at random, one line had a total of 19 operations, all of which were correct and tripped by instantaneous relays, and another line had a total of 54 operations, of which 57.4 per cent were by instantaneous relays. To date 43 circuit breakers have been equipped with these relays and no incorrect operations due to overreaching into the adjacent relay section have occurred.

On account of the necessarily high current settings which are required on these instantaneous overcurrent relays, there is no danger of their operation on system surges or oscillations. No operations of these devices under such conditions have been experienced. The conventional distance relays may, under certain conditions, trip their circuit breakers on the occurrence of system oscillations.[2]

Figure 3 shows a family of typical time-distance relay curves and instantaneous relay settings for 3 relay sections. By inspection of these curves the effectiveness of the instantaneous relays is readily apparent.

In a few cases the instantaneous relays are used to relay the entire length of the line for any value of fault current. For example, one 66 kv transmission line originates at a generating station, and the end of the relay section terminates in a transformer bank, then continues on at another voltage to an adjacent relay section. The impedance of the transformer bank introduces a relatively high impedance in the line. Obviously, the fault current from the generating station decreases abruptly at the transformer bank, which makes it possible to relay all faults up to the transformer bank instantaneously. The time

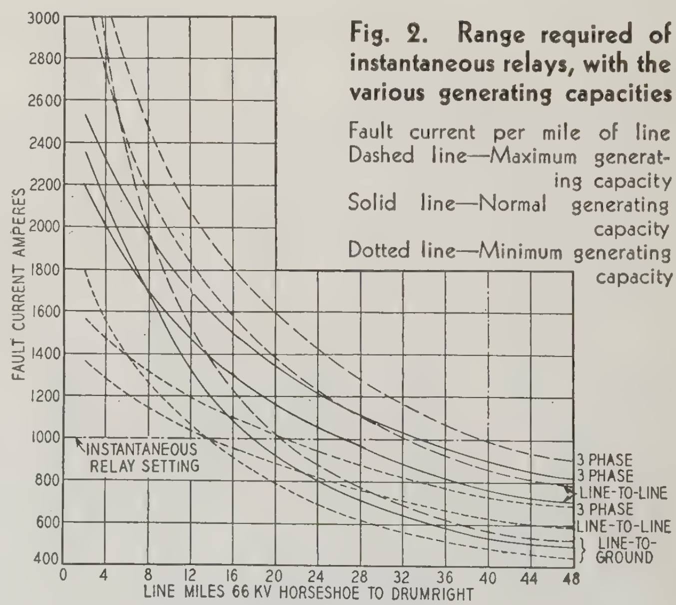

Fig. 2. Range required of instantaneous relays, with the various generating capacities

Fault current per mile of line
Dashed line—Maximum generating capacity
Solid line—Normal generating capacity
Dotted line—Minimum generating capacity

of the regular overcurrent relays can then be decreased materially and used only as back-up protection for the next relay section.

Use on Low Voltage Lines

The instantaneous relays have also been successfully adapted to distribution lines as low as 4 kv. Economies are realized from better coördination

between fuses located on the high voltage side of the transformer bank and relays of circuit breakers on the low voltage side. These relays permit quick tripping of the low-voltage circuit breaker with faults close to the transformer, and further provide better coördination between time delay relays, line sectionalizing fuses in the distribution line, and fuses of small transformer banks connected to the line at various points.

In order to establish instantaneous relay settings definitely, curves of fault current per mile of line, fuse and relay time-current characteristics are plotted upon the same coördinates to give a composite picture of the entire coördination problem. The time and trouble to prepare these data were repaid through fewer incorrect fuse operations.

Figure 4 will illustrate the point more clearly. In this case, without the use of instantaneous overcurrent relays, the time delay relay settings had to be raised sufficiently to allow a line sectionalizing fuse to clear. This then would allow the high voltage fuse to blow first on faults within a certain distance from the low-voltage circuit breaker, obviously an in-

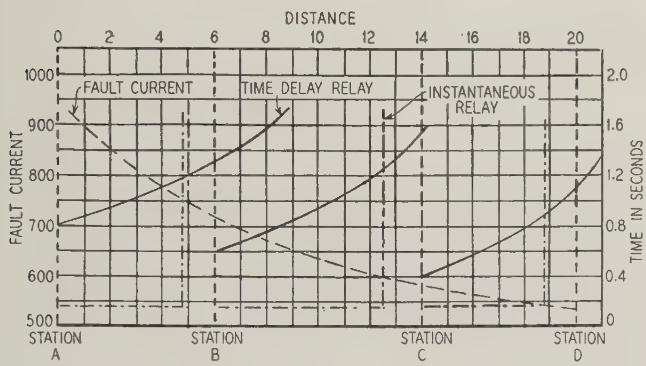

Fig. 3. Typical curves showing relationship between fault current and location of fault, and time-distance curves of instantaneous and time-delay overcurrent relays which are arranged to trip for power flow to a fault in the direction from station A to D

correct operation, with the loss of a costly high voltage fuse, and a prolonged outage due to the fuse blowing. There were only 2 alternatives available to remedy such a condition; either the size of the high voltage fuse had to be increased, or some means had to be provided to trip the circuit breaker more quickly. Since the high voltage fuse was of the correct size to protect the transformer properly, the instantaneous relays were installed and set to trip the breaker immediately with faults far enough out on the line to a point where the high voltage fuse could be coördinated properly with the time delay relays. It is apparent from the foregoing that such coördination will save fuses and also decrease circuit outages since the greater percentage of faults are of transient nature which will permit reclosing the circuit breaker immediately.

Instantaneous relays are also used in connection with bus fault relays. The instantaneous relays trip immediately when bus faults occur and the regular time delay relays act as back-up protection for the low-voltage circuit breakers. This not only shortens the duration of a system disturbance, but lessens the damage to equipment.

Summary

The use of instantaneous overcurrent relays on the Oklahoma Gas and Electric Company system has grown rapidly and problems of relay coördination,

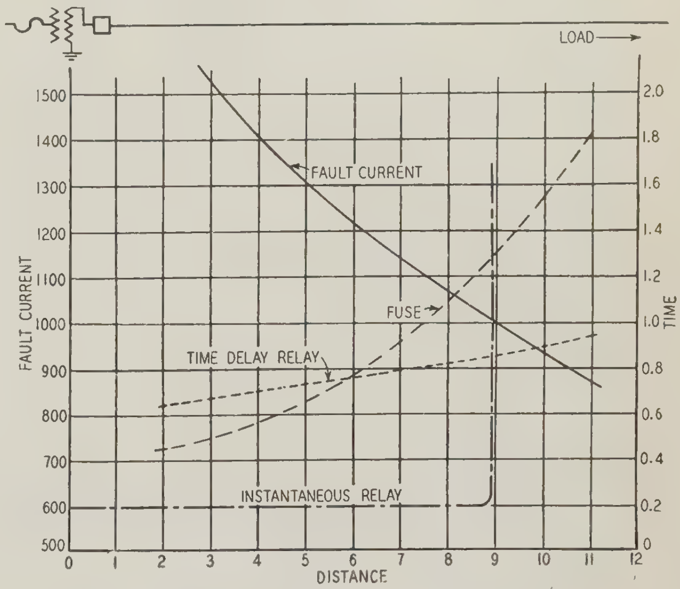

Fig. 4. Typical curves showing relationship between fault current and location of fault, and time-distance curves of instantaneous and time-delay overcurrent relays and fuses

although numerous, have been greatly simplified. These relays are now applied throughout the transmission and distribution system in connection with the present time delay relays and fuses. However, it would not have been practical to adapt these relays to the system unless a short-circuit calculating board was at all times available, as their proper operation depends upon an accurate knowledge of short-circuit current values under all conditions.

In conclusion, instantaneous relays have materially improved system stability, prevented long low-voltage dips, the loss of large blocks of load during fault conditions, and have improved utility service to the customer. The relatively small investment in these relays has been justified. They have also made possible the discontinuance of several pilot wire relay systems[3] operating over leased wire telephone lines at a saving of approximately $3,400 per year for the 193.5 miles of leased wire circuits which were used.

References

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2. Distance Relay Action During Oscillations, E. H. Bancker and E. M. Hunter. Elec. Engg. (A.I.E.E. Trans.), v. 53, July 1934, p. 1073–80.

3. Relaying With 2 Pilot Wires, C. H. Frier. Elec. Engg., v. 50, 1931, p. 824–6.

Calculation of Power Flow and Bus Voltages

The method for calculation of power flow and bus voltages in a-c networks described in this paper is based upon Kirchhoff's laws, and is novel mainly in that the power losses are lumped at the network terminals in determining power flow. The effect of circuit shunt capacitance is included. Problems in which the ratio of resistance to reactance in all branches is constant, and also problems in which this ratio is not constant are considered. The method can be applied to any a-c network.

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IN developing the lumped loss method described herein for the calculation of power flow and bus voltages in a-c networks, the aim was to set up some definite plan of procedure by which one might solve analytically any a-c network (transmission, distribution, etc.) for power flow and bus voltages. It was desired that the accuracy of results obtainable be comparable with that obtainable on an a-c calculating board, and that the cost of making the analytical solution be less than the cost of obtaining a solution on the a-c calculating board. In the former case, the cost would be entirely labor cost, while in the latter it would also include either rental charges or carrying charges on an a-c calculating board.

It should be understood that the method presented herein is not supposed to be a "short hand" method. In a complicated network the labor involved will be considerable. However, it is felt that one might as well face the facts in that the solution of a complicated network by *any* method (including the method using the a-c board) must necessarily involve considerable labor.

The networks to be dealt with may be considered to fall into 2 general classes: Those in which all circuits or branches involved have, or may be assumed to have, the same ratio of resistance to inductive reactance; and those in which the circuits or branches have different ratios of resistance to inductive reactance. Accordingly, the method of solution described in the following will be divided into:

Case I. Branches have the same ratio of resistance to inductive reactance.

Case II. Branches have different ratios of resistance to inductive reactance.

Charging current of the circuits involved will be taken into account.

In order to apply this method of solution to a particular network the following information must be at hand:

Inputs and outputs of the network.
Nominal voltage.
Circuit data, etc.
Operating voltage for some one bus point.

General Method of Procedure

Suppose the current values of all the inputs and outputs in a network are known. It can be shown that the correct flow of current in the different branches may be obtained by applying the principle of superposition[1,2] as follows:

Let each of the current inputs and outputs be resolved into 2 components, one component being in phase with some reference vector, and the other component being in quadrature with the same reference vector.

Considering only the "in-phase" components of current, solve for current flow in the branches of the network by means of Kirchhoff's laws. Similarly, considering only the "quadrature" components of current, solve for current flow in the branches of the network. For any branch of the network, then, the total current flow will be given by the sum of the corresponding "in-phase" and "quadrature" components.

In the case where all branches of the network have the same ratio of resistance to inductive reactance, it is not necessary to use the complex value of the impedances of the branches in calculating the current flow. Instead, simply resistance, reactance, or impedance magnitude may be used. Besides reducing the labor necessary in an analytical solution, this simplification permits the determination of current flow by means of a d-c calculating board, when one is available.

Thus having determined total current flow in the branches of the network, and knowing the voltage at any one bus point, the voltages at all other bus points can be calculated.

If, however, the inputs and outputs for the network are given in real power units and reactive power units,* such as kilowatts (kw) and reactive kilovoltamperes (rkva), and the voltage is known at only one bus point, then some voltage must be assumed for all other bus points before current values for the network inputs and outputs can be determined. Voltage assumptions must be governed by the fact that total current input must always equal total current output. Generally, in the original data,

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1. For all numbered references see list at end of paper.

* Throughout the rest of this paper the following nomenclature and units will be used:
"Real power" or simply "power"—kilowatts
"Reactive power"—reactive kilovoltamperes
"Total power"—kilovoltamperes

total kilowatt and reactive kilovoltampere input is given equal to total kilowatt and reactive kilovoltampere output, and directions are given for the allocation of the supply of losses. Before the supply of losses can be allocated, however, the value of the losses themselves must be determined. The following will show how the losses may be determined (approximately) and their effect included:

In the first place, the total loss in a circuit is made up of the following components:

Real Power Loss
- Due to series resistance (P_L)
- Due to shunt resistance (Leakage)

Reactive Power Loss
- Inductive reactive power loss, due to series inductance (Q_L)
- Capacitive reactive power loss, due to shunt capacitance (Q_c)

Series Resistance Power Loss. This component is determined simply by multiplying the series resistance R of the circuit by the square of the total current flowing through the circuit. It may be called "circuit power loss," P_L.

Shunt Resistance Power Loss (*leakage*). This component is negligible in practically all problems.

Series Inductance Reactive Power Loss. Determined by multiplying the series inductive reactance X_L of the circuit by the square of the total current flowing through the circuit. This may be called "circuit inductive reactive power loss," Q_L.

Shunt Capacitance Reactive Power Loss. Determined by multiplying the shunt capacitive susceptance by the square of the voltage across the circuit. This may be called "circuit capacitive reactive power loss," Q_c, or simply "charging reactive kilovoltamperes."

The kilowatt input to the circuit will differ from the kilowatt output by the amount P_L.

Q_L, of course, is "lagging" reactive power, while Q_c is "leading" reactive power. If leading reactive power is represented by "+rkva" and lagging reactive power by "−rkva," then the reactive kilovoltampere input to the circuit will differ from the reactive kilovoltampere output by an amount equal to the algebraic sum of Q_c and Q_L. Then, P_L, Q_L, and Q_c, are real and reactive loads which are distributed over the length of the circuit. In calculating the real and reactive power flow in a network, the effect of P_L, Q_L, and Q_c for any branch is approximated if $^1/_2\, P_L$, $^1/_2\, Q_L$, and $^1/_2\, Q_c$ is lumped at each end of the branch. (See Appendix A.)

In order to determine P_L, Q_L, and Q_c for any circuit, the current through the circuit and the voltage across the circuit must be known. As previously stated, the voltage is given for only one bus point, and voltages must be assumed for all other bus points. Having done this, charging reactive kilovoltamperes Q_c can be calculated and lumped at the bus points. The lumped charging rkva can then be combined with the actual inputs or outputs at the respective bus points. Original reactive kilovoltampere inputs and outputs must now be revised in order to allow for the supply of this charging reactive kilovoltamperes. Using the resulting net inputs and outputs in kilowatts and reactive kilovoltamperes, and the assumed bus voltages, current inputs and outputs can be determined and the network solved for current flow. From this current flow solution, a first approximation for P_L and Q_L can be calculated for each branch in the network. For each branch, then, $^1/_2\, P_L$ and $^1/_2\, Q_L$ is lumped at the 2 terminal bus points. After this is done throughout the network, the original local load (including charging reactive kilovoltamperes) or generation at each bus point may be combined with the total "circuit power loss" P_L and "circuit reactive power loss" Q_L which has been lumped at that bus point. This means that the total output of the network (useful load plus losses) is increased. In order to make total input and output for the network again equal, we must either increase the input figures or decrease the figures for *useful* output. This may be done all at one bus point or at several different points, according to directions in original data for supply of losses. New current flow in the network may now be determined (using assumed bus voltages as before). This process is repeated until the loss figures obtained in the last step do not differ too much from those in the preceding step.

From the final current flow in the network and the one specified bus voltage, all other bus voltages are now calculated. Using these calculated bus voltages, new values for current input and output may be obtained and the solution repeated. Each repetition of the solution should give more accurate results. In many cases the results from the first solution are accurate enough.

Detailed Method of Procedure for Case I

Given:

Inputs and outputs of the network in kilowatts (kw) and reactive kilovoltamperes (rkva), nominal voltage, circuit data, etc. Total inputs and outputs given equal.

Voltage specified for some one bus point.

Names of bus points at which losses are to be supplied.

Assumptions:

All circuits in the network have the same ratio of resistance to inductive reactance.

Preliminary Procedure

Determine the impedance for each branch of the network.

It should be kept in mind that, given the above mentioned information, accurate results must necessarily result from a series of solutions involving certain approximations. These approximations become more accurate in the successive solutions. The number of solutions required depends upon the accuracy desired in the results.

First Power Flow Solution

In order to approximate current values at the various input and output points of the network, assume for the moment that the nominal voltage exists at each bus point and all bus voltages are in

phase. This assumption permits power or reactive power values to be treated as current values. Using these kilowatt "current" values, solve for power flow by means of Kirchhoff's laws.

Charging Reactive Kilovoltamperes

Charging reactive kilovoltamperes Q_c for any circuit depends upon size of conductors, spacing of conductors, and operating voltage. (For this solution the voltage is assumed the same over the entire length of a circuit.) Charging reactive kilovoltamperes per mile of circuit may be calculated or may be read directly from tables.[4]

Assuming nominal voltage, determine charging reactive kilovoltamperes Q_c for each branch in the network. For each branch, lump $^1/_2$ Q_c at each terminal bus point. Combine the total charging reactive kilovoltamperes lumped at each bus with the actual reactive kilovoltampere input or output. Revise the input or output figures at the bus points at which losses are to be supplied, so that total reactive power input again equals total reactive power output.

Table I—First Loss Table

			Total Resistance and Reactance in Ohms			For 3 Phases (All Circuits)			
						Branch Load		Branch Losses	
Network Branch	No. of Circ.	Length in Miles	R	X	En Kv	P Kw	Q Rkva	P_L Kw	Z_L Rkva
A-B	3	33	3.06	9.0	110	58,000	4,000	850	−2,500

First Reactive Power Flow Solution

As before, assume all bus voltages to be in phase and equal to nominal voltage. Treating the reactive power values as "current" values, solve for reactive power flow by means of Kirchhoff's laws.

P_L and Q_L for First Power and Reactive Power Flow Solutions

For each branch of the network calculate the power loss P_L and inductive reactive power loss Q_L due to the flow of power P and reactive power Q through the branch. Assume nominal line to line voltage E_n in these calculations. For 3-phase circuits the following equations apply:

$$P_L = (P^2 + Q^2)\frac{R}{1{,}000E^2_n} \text{ kilowatts (3-phase)} \tag{1}$$

$$Q_L = (P^2 + Q^2)\frac{1{,}000E^2_n}{X_L} \text{ inductive reactive kilovoltampere (3-phase)} \tag{2}$$

In eqs 1 and 2, R and X_L are in ohms to neutral, E_n is in kilovolts from line to line, and P and Q are in 3-phase kilowatts and reactive kilovoltamperes, respectively.

Since there may be any number of branches in the network, it will be convenient to tabulate all the different quantities used in determining P_L and Q_L as in Table I.

For each branch, lump $^1/_2$ P_L and $^1/_2$ Q_L at each terminal bus point. Revise all the original input and output figures to include the additional bus loads due to P_L and Q_L. Revise the input or output figures at the bus points at which losses are to be supplied, so that, after P_L and Q_L have been included, total input again equals total output.

Second Power and Reactive Power Flow Solutions

Using the new input and output figures for the network, solve again for power flow and reactive power flow. Nominal voltage assumed for all bus points as before.

P_L and Q_L for Second Power and Reactive Power Flow Solutions

Draw up the "second loss table" using the figures from the second power and reactive power flow solutions. Nominal voltage assumed for all the bus points as before.

π-Line Total Power Flow Diagram

In calculating voltage drops in the different branches of the network, charging reactive kilovoltamperes may be left lumped at the bus points, but circuit power and reactive power loss must be distributed over the length of each branch—nominal π-line voltage calculations. Therefore, if additional power and reactive power flow solutions appear unnecessary, the next step is to take the power and reactive power loss quantities off of the different busses and redistribute them over each branch. The resulting total power flow figures may be considered to represent "π-line total power flow." This π-line total power flow is obtained by means of the *first* "loss table" and the *second* power and reactive power flow diagrams. In each branch of the network the sending end and receiving end kilovoltamperes should differ by an amount equal to P_L and Q_L. Following is an illustration:

Consider a branch *A-B* (*A* and *B* being the designation for the 2 terminal busses). Refer to Table I. Assume the second power flow solution gave a flow of 57,500 kw from *A* to *B*. Then *B* is the receiving end for branch *A-B*. Assume the second reactive power flow solution gave a flow of 4,800 leading rkva ($+j4{,}800$) from *B* to *A*. This is the same as 4,800 lagging rkva ($-j4{,}800$) from *A* to *B*. From Table I, $P_L = 850$ kw and $Q_L = -2{,}500$ rkva.

Then

$$\text{sending end real power} = 57{,}500 + \frac{850}{2} = 57{,}925 \text{ kw}$$

$$\text{sending end reactive power} = -4{,}800 + \frac{-2{,}500}{2} = -6{,}050 \text{ rkva}$$

$$\text{receiving end real power} = 57{,}500 - \frac{850}{2} = 57{,}075 \text{ kw}$$

$$\text{receiving end reactive power} = -4{,}800 - \frac{-2{,}500}{2} = -3{,}550 \text{ rkva}$$

In case more than 2 power and reactive power flow solutions are made, the total power flow diagram should be obtained from the last power and reactive power flow diagrams and the "loss table" corresponding to the next to last power and reactive power flow diagrams.

First Voltage Calculation

In order to calculate bus voltages, there must be a starting point or "reference point." This starting point will be the bus for which the voltage was specified, and the phase angle of the voltage at this point will be zero (reference voltage). Using this reference voltage, and the values of sending or receiving end kilovoltamperes in the branches terminating at this bus point, the magnitudes and phase angles of the voltages at adjacent bus points can be determined. Similarly, using these newly determined voltages, the voltages at other bus points can be calculated.

In calculating the voltages on the busses in any loop of a network, calculations should be made all around the loop and back to the starting point. If this last voltage determined is not the same, both in magnitude and angle, as the voltage started with, the loop does not "close." Of course, for most purposes, the loop does not have to close exactly. Judgment must be used in deciding how great a differential voltage can be tolerated. Failure of a loop to "close" may be due to errors in calculations, or the fact that the ratio of circuit resistance to circuit inductive reactance is not the same throughout the network. If the difference is too great, and there is no error in any of the calculations, power flow or reactive flow or both should be shifted in such a way as to remedy the situation. The necessary shift in power or reactive power flow may be approximated as being the kilovoltamperes corresponding to the current obtained by dividing the differential voltage by the total impedance of the path around the loop. (This principle of superimposing circulating currents has also been used in references 5 and 6.) Of course, both the differential voltage and the impedance must be used in their complex form.

Successive Solutions

After the bus voltages have been obtained in the above manner, the *input* and *output* figures (kilowatts and reactive kilovoltamperes) in the π-line total power flow diagram may be converted into current values (magnitude and angle). The phase angles of these currents, of course, will all be referred to the voltage reference vector. All the current inputs and outputs must now be resolved into 2 components, one component in phase with the reference vector (in-phase current), and one component in quadrature with the reference vector (quadrature current). The total "in-phase" current inputs must equal the total "in-phase" current outputs. Likewise the total "quadrature" current inputs must equal the total "quadrature" current outputs. If these conditions do not already exist, they must be obtained by adjusting the currents *at the busses which are supplying the losses*. This last is done based upon the assumption that power and reactive power input (or output) is directly proportional to in-phase and quadrature current input (or output) respectively. This, of course, is not strictly correct, but is near enough so for this purpose.

Having made total current input equal total current output, separate solutions of the network are then made for in-phase current flow and for quadrature current flow. These solutions are made in the same manner the power flow and reactive power flow solutions were made. Using the resulting in-phase and quadrature current flow diagrams and the one specified bus voltage, all other bus voltages are again calculated. (Second voltage calculation.)

At each bus point, convert current input or output into power and reactive power input or output, using the bus voltage obtained from the second voltage calculation. These power and reactive power input or output figures should agree with those given in the original data for each bus point, except the ones at which losses were to be supplied. Total input and total output should differ by an amount equal to the total losses in the network.

If the above conditions do not exist, again convert the input and output figures in the π-line total power flow diagram into current values (use the voltages obtained in the *second* voltage calculation). As before, the total current input must be made equal to total current output. Solve again for current flow and calculate new bus voltages (third voltage calculation). Convert current inputs and outputs into power and reactive power input or output, and compare with the input and output figures in the original data as before.

The number of successive solutions necessary depends upon the accuracy required. In many cases, the results represented by the π-line total power flow diagram and the first voltage calculation will be sufficiently accurate.

Detailed Method of Procedure for Case II

In the case where the network is made up of branches not having the same ratio of resistance to inductive reactance, current division will be inversely proportional, *not* to the magnitude of the impedance, but to the complex value of the impedance. It follows, then, that the d-c calculating board cannot be used as in Case I. Also, since complex values of impedance must be used, little or nothing would be gained in making separate solutions for "in-phase" and "quadrature" currents as was done in Case I. Current division in the network must be obtained either analytically (using Kirchhoff's laws) or by means of the a-c calculating board.

Following is the method of procedure for Case II. The reader will find some repetition of statements made under Case I. This was done to avoid the possibility of misunderstanding, and to make the procedure for each case complete in itself.

Given:

Inputs and outputs of the network in kilowatts and reactive kilo-

voltamperes, nominal voltage, circuit data, etc. Total inputs and outputs given equal

Voltage specified for some one bus point.

Names of bus points at which losses are to be supplied.

Preliminary Procedure

Determine the impedances of each branch.

Charging Reactive Kilovoltamperes

Assuming nominal voltage, determine charging reactive kilovoltamperes Q_C for each branch, as was done in Case I. For each branch, lump $^1/_2\, Q_c$ at each terminal bus point. Combine the total charging reactive kilovoltamperes lumped at each bus with the actual reactive power input or output. Revise the input or output figures at the bus points at which losses are to be supplied, so that total reactive power input again equals total reactive power output.

First Total Power Flow Solution

Assume nominal voltage exists at each bus point and all bus voltages are in phase. This assumption permits total power input or output values to be treated as current values. Using these kilovoltampere "current" values, solve for total power flow analytically, using Kirchhoff's laws. Total power and impedance values must be used in their complex form. This means the solution of simultaneous equations involving complex numbers. The solution of these equations may be obtained in the conventional manner; however, it is felt that determinants can be used to advantage in this instance.

P_L and Q_L for First Total Power Flow Solution

Calculate power loss as was done in Case I, using eqs 1 and 2, and draw up the "first loss table."

For each branch, lump $^1/_2\, P_L$ and $^1/_2\, Q_L$ at each terminal bus point. Revise all the original input and output figures to include the additional bus loads due to P_L and Q_L. Revise the input or output figures at the bus points at which losses are to be supplied, so that, after P_L and Q_L have been included, total input again equals total output.

Second Total Power Flow Solution

Using the new input and output figures for the network, solve again for total power flow. Nominal voltage is assumed for all bus points as before.

P_L and Q_L for Second Total Power Flow Solution

Draw up the "second loss table," using the figures from the second total power flow solution.

π-Line Total Power Flow Diagram

Total power flow solutions and loss calculations are repeated until the loss figures obtained in the last step do not differ too much from those in the preceding step. When additional total power flow solutions appear unnecessary, the next step is to take the power and reactive power loss quantities off of the different busses and redistribute them over each branch. The resulting total power flow figures may be considered to represent "π-line total power flow." This π-line total power flow is obtained by means of the last total power flow diagram and the line losses corresponding to the next to last total power flow diagram. In each branch of the network the sending end and receiving end kilovoltamperes should differ by an amount equal to P_L and Q_L for that branch. See the illustration given in Case I.

First Voltage Calculation

As in Case I, the voltage calculations will be started from the bus for which the voltage was specified, and the phase angle of the voltage at this point will be zero (reference voltage). See "first voltage calculation" in Case I.

Successive Solutions

Having obtained all bus voltages, the *input* and *output* figures (in kilovoltamperes) in the π-line total power flow diagram should be converted into current values (magnitude and angle). The phase angles of these currents will all be referred to the voltage reference vector. Next, convert the current inputs and outputs from polar to complex form ("in-phase" and "quadrature" components). Total "in-phase" current inputs should equal total "in-phase" current outputs. Likewise, total "quadrature" current inputs and outputs should be equal. If these conditions do not already exist, they must be obtained by adjusting the currents *at the busses which are supplying the losses*.

Having made total current input equal to total current output, a new solution for current flow in the network is made. Using the values of current flow thus determined and the one specified bus voltage, all other bus voltages are again calculated (second voltage calculation).

At each bus point, convert current input or output into power and reactive power input or output, using the bus voltage obtained from the second voltage calculation. These power and reactive power input or output figures should agree with those given in the original data for each bus point, except the ones at which losses were to be supplied. Total input and total output should differ by an amount equal to the losses in the network.

As in Case I, the number of successive solutions necessary depends upon the accuracy required. In many cases, the results represented by the π-line total power flow diagram and the first voltage calculation will be sufficiently accurate.

General Notes

If enough is known about the network involved that an estimate can be made of the average value of the operating voltages of all bus points, this value

should be substituted for nominal voltage wherever the latter is used in the foregoing.

Whenever possible, problems should be solved by the method under Case I, since the amount of work involved will usually be less, and the chances of making errors will be smaller. No hard and fast rules can be set down as to how great a variation in the ratio of resistance to reactance can be tolerated under Case I. This will depend upon the network involved and the accuracy required in the results. In general, it might be stated that if the highest value of $\frac{R}{X}$ is not more than 10 per cent greater than the lowest value of $\frac{R}{X}$, and if fair accuracy is desired in results, Case I may be used. If only rough accuracy in results is desired, the difference between maximum and minimum values of $\frac{R}{X}$ may be 20 per cent. The above figures are given only as a rough guide; after having had some experience in solving problems, one should be able to set down his own tolerances, based on his own ideas of what would be called "accurate," "fairly accurate," or "rough" results.

This method has been applied to existing transmission networks. Results obtained are considered to be at least as accurate as those obtainable on an a-c calculating board.

Whether or not this method will be cheaper than the a-c board method, will depend upon the network considered and the number of different conditions to be studied, besides such factors as cost of using the a-c board, traveling expenses, wages, etc. In general, it appears that the a-c board method will be cheaper only when several different conditions are to be studied in a complicated network.

In Appendix *B* is shown a sample problem to which this method has been applied.

Appendix A

The following is given in case there is some question as to the validity of the method of lumping losses in determining power flow.

Perhaps the easiest way to justify this procedure, without going into too much detail, is to point out the similarity between the flow of current through the distributed shunt capacitance along a circuit, and the consumption of power (real and reactive) in the distributed series resistance and inductive reactance along the circuit:

Neglecting leakage, the receiving end current of any circuit will be less than the sending end current by an amount equal to the "charging" current (current flowing through the distributed shunt capacitance). This charging current can then be considered as lost current—"*current loss.*" Similarly the receiving end total power will be less than the sending end total power by an amount equal to the *power losses* in the circuit (I^2R and I^2X).

Assuming uniform voltage along the full length of the circuit, a plot of the current at any point in the circuit will be a straight line. Similarly, assuming uniform current along the full length of the circuit, a plot of the power (real and reactive) at any point will be a straight line.

Therefore, just as current loss (charging current) may be lumped one-half at each end of the circuits in a network in determining current flow, similarly, power losses may be lumped one-half at each end of the circuits in a network in determining power flow.

Assuming a case where actual operating data is available for loads and generation and for power losses in each branch of a network, and where charging current is lumped at the bus points, the process of lumping losses in determining power flow would be exact. However, in the problems which are intended to be handled by the method given in this paper, actual operating data would not be given. Instead, load and generation figures would be the result of estimates, and loss figures would not be given at all. As previously stated, the total of the load figures is usually given equal to the total of the generation figures. Hence, since the losses themselves have to be approximated, the power flow solutions which are determined from the results of these approximations must also be approximations. The errors decrease as the solution is repeated. In the calculation of power losses from power flow, the average of sending end and receiving end power is used (and nominal voltage is assumed). This procedure is accurate enough for the purpose.

Appendix B

In the following, a sample problem is solved to illustrate the method. For convenience "mega-" units are used. "Mega-" units equal "kilo-" units divided by 1,000.

GIVEN: Power transmission line network shown in Fig. 1. (Sixty cycles, 3 phase.)

Generation

Bus Point	Megawatts	Reactive Megavoltamperes
S	86.9	5.7 leading
R	222.7	76.5 leading
T	12.1	3.5 lagging
G	1.1	0.9 leading

Loads

Bus Point	Megawatts	Reactive Megavoltamperes
M	3.6	2.1 lagging
B	0.9	5.5 leading
H	4.4	3.5 leading
P	313.9	0.0

Synchronous Condensers

Bus Point	Capacity	Input to Condensers in Reactive Megavoltamperes
R	2—15.0 mva	0.0
M	2—15.0 mva	0.0
P	3—30.0 mva	72.7 leading

Voltage Specifications

Bus *R*	112 kv
Busses *S* and *T*	112–120 kv
Busses *M*, *G*, *B*, and *H*	111–114 kv
Bus *P*	109–113 kv

Assume nominal voltage to be 112 kv.

Supply of Losses

Circuit real power losses (megawatts) to be supplied from bus *P* (deducted from the load).

Circuit reactive power losses (reactive megavoltamperes) to be supplied from synchronous condensers at busses *R*, *M*, and *P*.

FIND

Real and reactive power flow in all branches.

Voltages at all bus points. (Both magnitude and phase angle.)

Necessary synchronous condenser settings.

The problem comes under Case II.

PROCEDURE

From the diagram of circuit data, Fig. 1, the values of branch impedances and charging reactive megavoltamperes are compiled; see Table II.

The first total power set-up, Fig. 2, may then be drawn, and the solution of current values i_1, i_2, and i_3 obtained. This is done by

writing the equation for the impedance drops around the 3 loops, and simplifying:

$$(13.98 + j\,46.48)i_1 - (3.65 + j10.58)i_2 - (3.65 + j10.58)i_3 - 407.6 + j539.2 = 0.0 \quad (3)$$

$$(3.65 + j\,10.58)i_1 - (17.77 + j66.33)i_2 - (8.49 + j\,33.49)i_3 + 270.0 + j10{,}160.0 = 0.0 \quad (4)$$

$$(9.28 + j\,32.85)i_2 - (3.2 + j19.55)i_3 + 274.1 - j\,97.5 = 0.0 \quad (5)$$

Solving eqs 3, 4, and 5 by determinants:

$i_1 = 43.0 - j\,4.2$
$i_2 = 80.4 + j24.8$
$i_3 = 140.1 + j14.7$

These values may then be inserted in the first total power flow diagram, Fig. 3, and the first loss table, Table III, may be compiled. New input and output figures for the network can then be determined as shown in Table IV, and the second total power flow set-up, Fig. 4, can be drawn. Solutions for new values of i_1, i_2, and i_3, can then be obtained from Fig. 4, by writing the equations for the impedance drops around the 3 loops, and simplifying, as follows:

Table II—Branch Impedances and Charging Reactive Megavoltamperes

Network Branch	R Ohms	X_L Ohms	Z Ohms	Charging Rmva at 112 Kv
R-S	4.5	13.2	14.1 /69.5°	4.35
S-T	4.64	17.05	17.66/74.8°	6.15
T-G	1.19	5.65	5.78/78.1°	2.15
R-M	2.65	7.7	8.15/71.0°	2.54
M-G	1.0	2.88	3.05/70.9°	0.98
R-B	2.45	7.15	7.55/71.1°	2.36
B-P	6.83	25.7	26.6 /75.5°	9.25
G-H	1.91	9.05	9.26/78.1°	3.45
H-P	2.93	13.85	14.15/78.1°	5.27
R-P	3.2	19.55	19.8 /80.7°	17.9
Total				54.4

Let total charging reactive megavoltamperes be supplied from bus *P*.

$$(13.98 + 46.48)i_1 - (3.65 + j10.58)i_2 - (3.65 + j10.58)i_3 - 232.26 + j\,447.77 = 0.0 \quad (6)$$

$$(3.65 + j10.58)i_1 - (17.77 + j\,66.33)i_2 - (8.49 + j\,33.49)i_3 + 605.0 + j\,9{,}904.0 = 0.0 \quad (7)$$

$$(9.28 + j\,32.85)i_2 - (3.2 + j19.55)i_3 + 43.7 - j104.6 = 0.0 \quad (8)$$

Solving eqs 6, 7, and 8 by determinants:

$i_1 = 42.2 - j\,0.6$
$i_2 = 80.2 + j19.7$
$i_3 = 136.2 + j15.0$

From these new values of current, the second total power flow diagram, Fig. 5, can be drawn, and the second loss table, Table V, compiled. Comparing Tables III and V, the loss figures are near enough the same that no further power flow solutions will be made. The next step is to draw up the first voltage and total power flow diagram, Fig. 6. The voltage calculations for Fig. 6 are shown in Table VI. The input in amperes, Table VII, can then be determined.

In terms of power and reactive power, the inequality between total input and total output, as shown in column 3, Table VII, is small enough that no further calculations will be made.

The final results, then, are represented on Fig. 6.

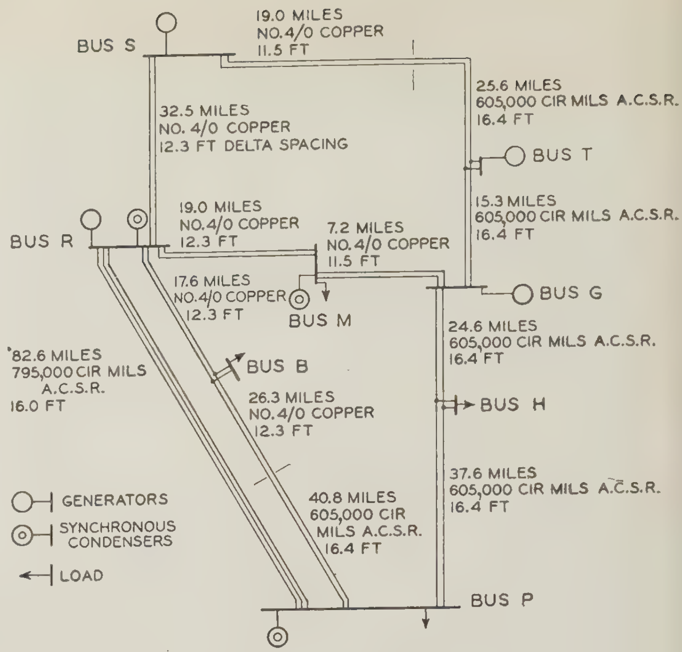

Fig. 1. Circuit data

Circuit data given is length, conductor size, and conductor equivalent delta spacing

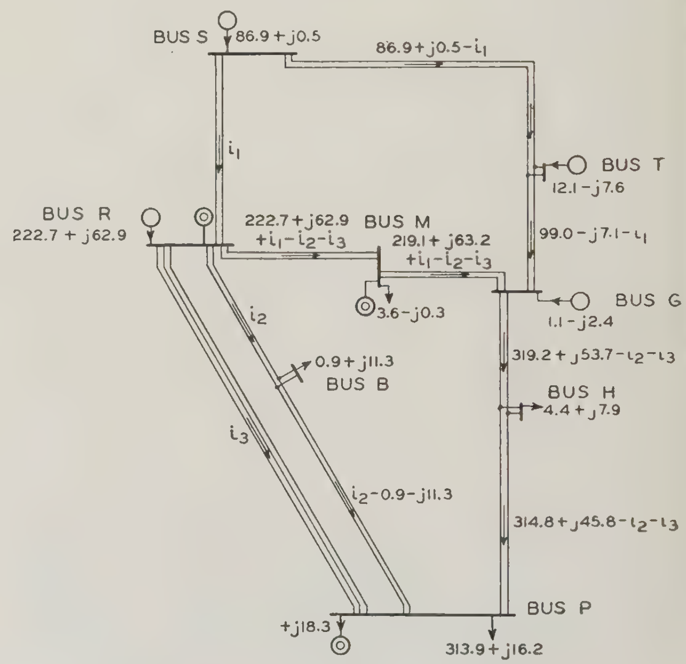

Fig. 2. First total power set-up

Power flow figures are in megawatts and reactive megavoltamperes
+j indicates "leading" reactive megavoltamperes

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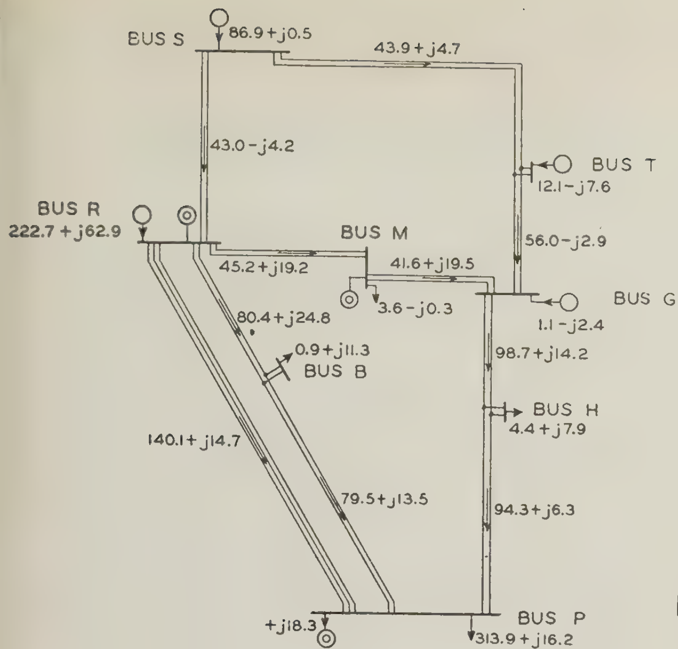

Table III—First Loss Table

Network Branch	Total Power Flow Mva	Voltage Assumed Kv	P_L Mw	Q_L Rmva
R-S	43.2	112.0	0.67	1.96
S-T	44.2	112.0	0.72	2.65
T-G	56.0	112.0	0.3	1.41
R-M	49.1	112.0	0.51	1.48
M-G	46.0	112.0	0.17	0.49
R-B	84.2	112.0	1.40	4.05
B-P	80.7	112.0	3.56	13.35
G-H	99.7	112.0	1.52	7.13
H-P	94.5	112.0	2.09	9.88
R-P	140.9	112.0	5.06	30.9
Total			16.0	73.3 lagging

Losses to be supplied as follows:
From bus *P*, deduct from load 16.0 mw
From bus *P*, synchronous condenser 38.3 rmva lagging
From bus *R*, synchronous condenser 30.0 rmva lagging
From bus *M*, synchronous condenser 5.0 rmva lagging

Fig. 3 (left). First total power flow diagram

Table IV—Determination of New Input and Output Figures for Network

Figures in Megawatts and Reactive Megavoltamperes

Bus Point	(1) Initial Output*	(2) Initial Input*	(3) Lumped Losses (excl. charging rmva)	(4) Supply of Circuit Losses	(5) Resultant Outputs	(6) Resultant Inputs
S	0.0 + *j* 0.0	86.9 + *j* 0.5	0.7 − *j* 2.3	0.0 + *j* 0.0		86.2 + *j* 2.8
R	0.0 + *j* 0.0	222.7 + *j*62.9	3.81 − *j*19.19	0.0 − *j*30.0		218.89 + *j*52.09
T	0.0 + *j* 0.0	12.1 − *j* 7.6	0.51 − *j* 2.03	0.0 + *j* 0.0		11.59 − *j* 5.57
G	0.0 + *j* 0.0	1.1 − *j* 2.4	0.99 − *j* 4.52	0.0 + *j* 0.0		0.11 + *j* 2.12
M	3.6 − *j* 0.3	0.0 + *j* 0.0	0.35 − *j* 0.98	0.0 − *j* 5.0	3.95 + *j* 3.72	
B	0.9 + *j*11.3	0.0 + *j* 0.0	2.48 − *j* 8.7	0.0 + *j* 0.0	3.38 + *j* 2.6	
H	4.4 + *j* 7.9	0.0 + *j* 0.0	1.8 − *j* 8.51	0.0 + *j* 0.0	6.2 − *j* 0.61	
P	313.9 + *j*34.5	0.0 + *j* 0.0	5.36 − *j*27.07	16.0 − *j*38.3	303.26 + *j*45.73	
	322.8 + *j*53.4	322.8 + *j*53.4	16.0 − *j*73.3	16.0 − *j*73.3	316.79 + *j*51.44	316.79 + *j*51.44

+*j* indicates "leading" reactive power.
−*j* indicates "lagging" reactive power.
* Columns 1 and 2 are obtained directly from Fig. 2, and, therefore, include the lumped charging reactive megavoltamperes.

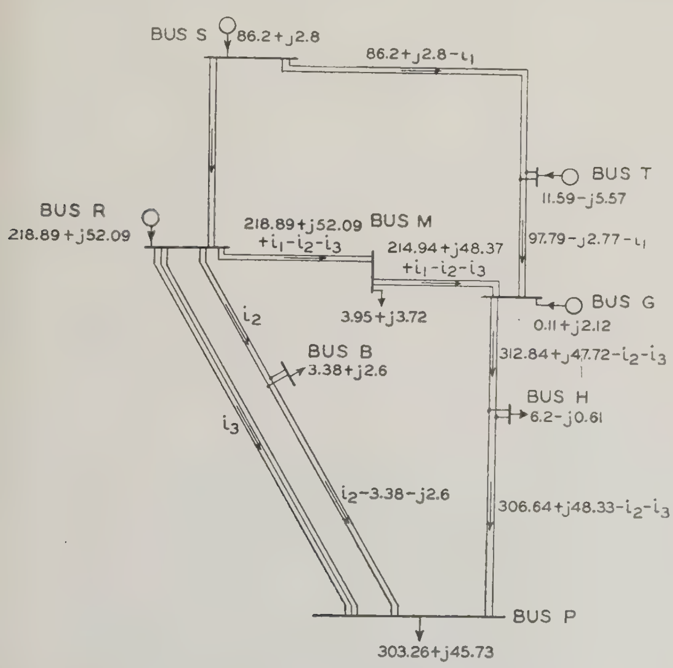

Fig. 4. Second total power flow set-up

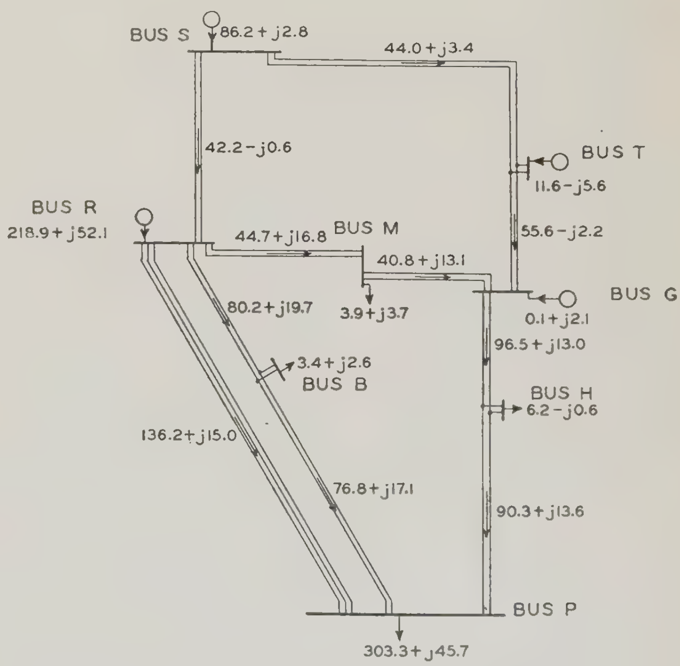

Fig. 5. Second total power flow diagram

Table V—Second Loss Table

Network Branch	Total Power Flow Mva	Voltage Assumed Kv	P_L Mw	Q_L Rmva
R-S	42.2	112.0	0.65	1.88
S-T	44.1	112.0	0.72	2.64
T-G	55.6	112.0	0.29	1.39
R-M	47.8	112.0	0.48	1.40
M-G	42.9	112.0	0.15	0.42
R-B	82.6	112.0	1.33	3.89
B-P	78.7	112.0	3.37	12.67
G-H	97.3	112.0	1.44	6.82
H-P	91.2	112.0	1.94	9.17
R-P	137.0	112.0	4 78	29.20

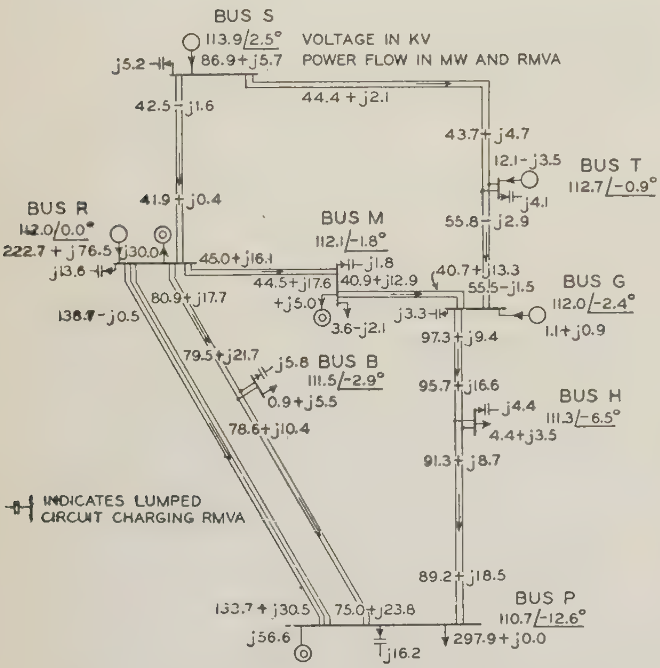

Fig. 6. First voltage and total power flow diagram (π-lines)

Bus voltage in kilovolts. Reference voltage is at bus R

Table VII—Determination of Inputs in Amperes

(1) Bus Point	(1) Bus Voltage Kv	(2) in Mva	(3) Net Bus Inputs (including charging rmva) in Amperes Referred to Reference Vector	(4) Revised Amperes Referred to Reference Vector
S	113.9/ 2.5°	86.9 + j 0.5	440.0 + j 21.5	440.0 + j 21.5
R	112.0/ 0.0°	222.7 + j32.9	1,147.0 + j169.5	1,147.0 + j181.4
T	112.7/− 0.9°	12.1 − j 7.6	61.4 − j39.9	61.4 − j 39.9
G	112.0/− 2.4°	1.1 − j 2.4	5.1 − j 12.6	5.1 − j 12.6
			1,653.5 + j138.5	1,653.5 + j150.4
M	112.1/− 1.8°	−3.6 − j 4.7	−19.3 − j 23.6	−19 3 − j 23.6
B	111.5/− 2.9°	−0.9 − j11.3	−7.6 − j 58.0	−7.6 − j 58.0
H	111.3/− 6.5°	−4.4 − j 7.9	−27.3 − j 38.1	−27.3 − j 38.1
P	110.7/−12.6°	−297.9 − j72.8	−1,600.0 − j 30.7	−1,599.3 − j 30.7
			−1,654.2 − j150.0	−1,653.5 − j150.4

As stated in title, the above is a table of bus *inputs*. Accordingly, a positive quantity represents an actual input, and a negative quantity an actual output. $+j$ indicates "leading" reactive power.
In column 3 the sum of positive quantities should equal the sum of the negative quantities (input equal to output). As seen above this condition does not exist. Current input figures are revised at busses P and R, as shown in column 4, to bring about equality.

Table VI—First Voltage Calculations

Point Branch	Z in Ohms	Mva_r	E_r in Kv	I Z in % of E_r Ref. to E_r	E_s in % of E_r Ref. to E_r	E_s in Kv Ref. to /0°	Mva_s	E_s in Kv	I Z in % of E_s Ref. to E_s	E_r in % of E_s Ref. to E_s	E_r in Kv Ref. to /0°	Average Voltage for Point in Kv
R-S	14.1 /69.5°	41.9/0.5°	112/0.0°	4.71/70.0°	101.75/2.5°	113.9/2.5°						
S-T	17.66/74.8°						44.5/ 2.7°	113.9/ 2.5°	6.06/77.5°	98.9 /− 3.4°	112.7/− 0.9°	
T-G	5.78/78.1°						55.9/− 3.0°	112.7/−0.9°	2.54/75.1°	99.35/− 1.4°	111.9/− 2.3°	
R-M	8.15/71.0°						47.8/ 19.7°	112.0/ 0.0°	3.11/90.7°	100.1 /− 1.8°	112.1/− 1.8°	
M-G	3.05/70.9°						42.9/ 17.5°	112.1/−2.3°	1.04/88.4°	99.9 /− 0.6°	112.0/− 2.4°	
G												112.0/− 2.4°
R-B	7.55/71.1°						82.8/ 12.3°	112.0/ 0.0°	4.99/83.4°	99.5 /− 2.9°	111.5/− 2.9°	
B-P	26.6 /75.5°						79.3/ 7.5°	111.5/−2.9°	16.98/83.0°	99.4 /− 9.8°	110.8/−12.7°	
G-H	9.26/78.1°						97.7/ 5.5°	112.0/−2.4°	7.21/83.6°	99.4 /− 4.1°	111.3/− 6.5°	
H-P	14.15/78.1°						91.7/ 5.4°	111.3/−6.5°	10.48/83.5°	99.35/− 6.1°	110.6/−12.6°	
R-P	19.8 /80.7°						138.7/− 0.2°	112.0/ 0.0°	21.9 /80.5°	98.8 /−12.6°	110.7/−12.6°	
P												110.7/−12.6°

A Criterion of Quality of Cable Insulation

Radial uniformity of oil impregnated paper cable insulation, that is, uniformity in a radial direction from conductor to sheath, is a characteristic of well manufactured cable that is fully as important or more so than longitudinal uniformity. Radial power factor curves for several brands of new cable included in this paper show marked irregularities which are attributed to poorly controlled manufacturing methods. On the basis of such studies, some manufacturers have made efforts to improve the radial uniformity of their insulation with resulting great improvement in quality. This characteristic of cable insulation thus provides a criterion of insulation quality that should be useful to both manufacturer and user.

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OF ALL the characteristics of oil-impregnated paper-insulated cable that make for quality the one upon which the electrical industry has placed most emphasis is uniformity. On each batch of cable the variation of insulation resistance and power factor is watched carefully from reel to reel. This is a check on uniformity, but in a longitudinal direction only. Until recently, uniformity of new cable insulation never had been determined in a radial direction, that is, along a radius between conductor and sheath, probably because apparatus for precise measurements was not available. Methods for measuring electrical and chemical characteristics in a radial direction were developed, however, in the course of researches on the deterioration of high voltage cable insulation.[1] When these methods were applied to cables of all types and all ages, it was found that not only was the insulation of used cables nonuniform in a radial direction, but also the insulation of most new cables was radially nonuniform. Only cable manufactured under the most careful conditions approached radial uniformity. Radial uniformity of new cable insulation is thus a valuable criterion of the quality of new cable, just as lack of radial uniformity of used cable is a criterion of the degree of deterioration. Recognition of this important cable characteristic should prove a boon to the cable manufacturer anxious to improve his product. It also should serve as a valuable guide to the purchaser of cable in judging the care that has been taken in the selection of materials and in methods of manufacture.

A paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. summer convention, Ithaca, N. Y., Apr. 24–28, 1935. Manuscript submitted Feb. 19, 1935; released for publication March 1, 1935.

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Radial Method of Examination

The usefulness of the radial method of examining cable insulation was first demonstrated in tracing the source and nature of deterioration in the insulation of high voltage cables from service. It consists in measuring the power factor and the degree of oxidation of the individual paper tapes taken one by one between the conductor and the sheath of a cable. For measuring the power factor of the single paper tapes, a cell that can be used in a routine manner and that gives reliable results has been devised. The degree of oxidation of the oil removed[2] from the individual tapes is determined on an Adam balance using the hydrophil or water spread method based upon the pioneer work of Langmuir.[3] With the use of these 2 instruments radial power factor and oxidation curves can be obtained which, in the absence of moisture, are roughly U-shaped.

The similarity between the power factor and hydrophil curves indicates the likelihood that the high power factor near the conductor and sheath is caused by some form of oxidation. Occasionally abnormal radial curves are obtained, and from their shape and the degree of correspondence between the power factor and oxidation curves much may be learned as to the nature and source of deterioration. Not least among the results of the radial method of examination has been the elimination of many academic theories of deterioration from practical consideration. (This remark applies only to cable for use up to 66 kv that has insulation of the standard thickness. Without question, at higher stresses additional mechanisms of deterioration become of importance.)

Application of Radial Method to New Cable

On applying the radial method of examination to new cables, curves frequently were obtained that were similar in shape to those for used cables, the upturns near the conductor and sheath, however, being far less pronounced. Typical curves showing the variation in radial power factor for new and used cable are given in figure 1. The lowest curve represents the most uniform radial characteristics observed so far in any cable yet tested.

In comparing the radial power factor curves in figure 1, attention should be directed to the following items: The triangular areas *abc* and *def* under the upturns at either end of the curve represent a deterioration of the insulation, and it is important to note the distance that they penetrate into the insula-

tion. The heights *ab* and *ef* of the 2 triangles are of interest since these appear to represent the locations of maximum concentrations of the substance causing high loss. The middle portion of the curve, *cd*, probably represents the best insulation that can be obtained with the component materials under the given conditions of manufacture. Some importance may be attached to the degree of regularity of the

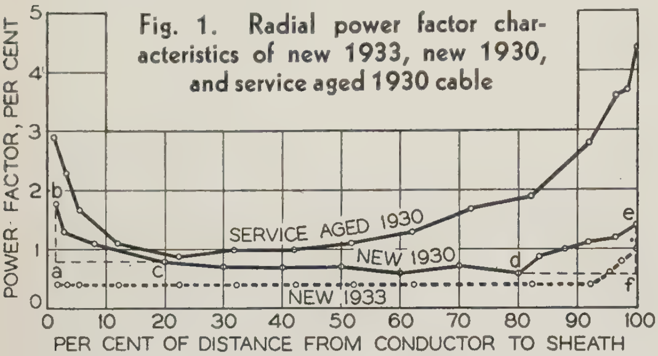


Fig. 1. Radial power factor characteristics of new 1933, new 1930, and service aged 1930 cable

cd portion of the curve as information often may be gained from it as to conditions of manufacture.

The foregoing findings resulted in the decision to investigate the radial characteristics of several brands of new cable. Six manufacturers were approached on the subject of submitting samples of cable that would represent their best 1933 practice, and were fully instructed to take all necessary precautions in protecting the samples from contamination caused by certain forms of end sealing and exposure to air. These samples were duly received and all necessary precautions were taken in the laboratory to prevent undue exposure to air or contamination. Therefore any results obtained in the diagnostic studies should represent the true characteristics of the cable as manufactured.

Results of the study of these 6 brands of new 24-kv 3-conductor cable are represented graphically in figure 2. The curve for only one conductor of each cable is shown, the curves for all 3 usually being similar in character. All the curves exhibit an upturn at both conductor and sheath. The curve having the lowest power factor and the greatest uniformity is that of brand *A* cable. Brand *B* follows closely upon *A* with regard to radial uniformity, and its excellence follows likewise from careful factory control. Both *A* and *B* are impregnated with mineral oil alone. This fact probably accounts for the special precautions taken in manufacture, since the use of rosin considerably increases the dielectric loss, thereby masking small variations in manufacture.

The 4 remaining brands of cable contained rosin, which accounts for the higher average power factor when compared with that of the 2 mineral oil cables. The curve for brand *C* is irregular in its middle portion; this cable, however, shows a reasonably small upturn of the curve at either end. Brand *D*, despite its having the highest average value of power factor of any, exhibits remarkably good radial uniformity except in close proximity to the conductor and sheath; its high loss may be attributed to the amount or grade of rosin used in the impregnating oil. A different characteristic is found in brand *E*, where the high loss or "deterioration triangles" penetrate unusually deeply into the insulation. Several undesirable features are indicated in the curve for brand *F*. It exhibits high power factor next to the sheath, high average value of power factor, a "deterioration triangle" that penetrates deeply into the insulation at the copper, and an irregular power factor in the intermediate portion of the curve. Lack of uniformity may be characteristic of this brand of cable since similar curves recently have been obtained by another investigator[5] on cables made in the same factory at different times during the last 8 years.

Causes of Radial Nonuniformity

The cause of the upturn in some of the radial power factor curves possibly may be explained by the radial oxidation curves. The general correspondence between the radial power factor and radial oxidation or hydrophil curves of figure 3 for a mineral oil cable suggest that the upturn in power factor at the sheath results from oxidation of the oil. The explanation appears to be reasonable since as the cable passes through the lead press some oil from the insulation touching the hot lead in the presence of air undoubtedly becomes oxidized as it flows backward over the incoming new insulation. Oxidation products in the oil, formed either at the lead press or in the oil prior to leading, are probably chiefly responsible for the increases in power factor.

Another cause of increased power factor of the paper layers next to the lead sheath may be the absorption of moisture if there is a prolonged exposure of the impregnated cable to factory atmosphere previous to leading. In some cables contamination by dirt may be a factor. The interval between various factory operations occasionally may be long enough to permit dust or metallic particles to accumulate on the surface of the insulation. In some

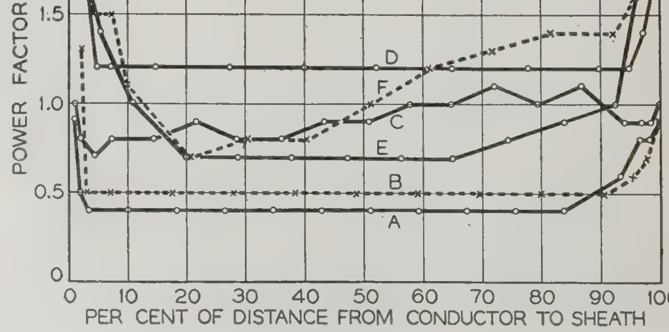


Fig. 2. Radial power factor curves for new 1933 type H cable from 6 manufacturers, measured at 60 degrees centigrade and 50 volts per mil

factories the cable is submerged just before leading in an oil bath in the floor, and it is possible for foreign material from the floor to become mixed with the oil, thus contaminating the outer layers of insulation.

The cause of the irregularity in the middle portions of the radial power factor curves usually may be traced to the manner in which the cable is dried, degassed, and impregnated, and in a lesser degree to the type of saturant and paper used. For example, in figure 2 the radial characteristics of the several brands of cable may be interpreted in terms of materials or manufacturing methods then in use. One manufacturer uses an inert gas at one stage of manufacture to displace residual air in the insulation in order to reduce oxidation and to improve the thoroughness of impregnation. Another manufacturer uses different types of paper to effect a so-called "graded" insulation. Another manufacturer expends considerable effort toward thoroughly degassing both oil and paper. Special apparatus has been installed for frequently filtering and purifying the oil. Still another manufacturer utilizes a process in which, after the paper insulated core has been dried and evacuated, the vacuum is broken and air again allowed to rush in. After a short period, said not to exceed 10 minutes, the cable is plunged into the impregnating tank. This procedure probably results in small amounts of air being trapped in the insulation and the resulting oxidation of the oil might account for the variations shown by the radial power factor curve. One of the cables is made by the "pan-saturation method." In this method each reel of cable is placed in a separate pan for impregnation. Upon removal from the impregnating tank the pan accompanies the cable so that the cable remains immersed in the oil in which it was impregnated right up to the moment it enters the lead press. In this way the absorption by the insulation of air and moisture from the factory atmosphere during unavoidable delays is minimized. It will be evident from the foregoing that a variety of methods of degassing and impregnation are prevalent in the cable industry.

Significance of Radial Nonuniformity

The significance of the radial curves lies in the information they give regarding the care used in manufacturing. Poor materials, outmoded methods of manufacture, or undue exposure to the factory atmosphere as well as the use of good materials and good practice will be indicated in the radial characteristics.

At present the irregularities in the radial curves that some conditions of manufacture produce cannot be evaluated directly in terms of operating life; but where 2 brands of cable are under consideration, one exhibiting highly erratic radial characteristics, indicating poorly controlled conditions of manufacture, and the other having uniform radial curves of low value, indicating careful and studied manufacturing methods, the likelihood of long life in service is much greater for the radially uniform cable. This conclusion is supported by another investigator's[5] observation that initial peaks in radial power factor curves of new cable become much more pronounced after a period of service. In those cables in which errors in manufacturing methods can be detected by the radial power factor test, it is probable that other errors, which cannot be detected by present available means, also are present. Radial uniformity of cable insulation, therefore, may be considered as an indication of quality.

Fig. 4. Effect of modified manufacturing methods on the radial characteristics of brand F cable

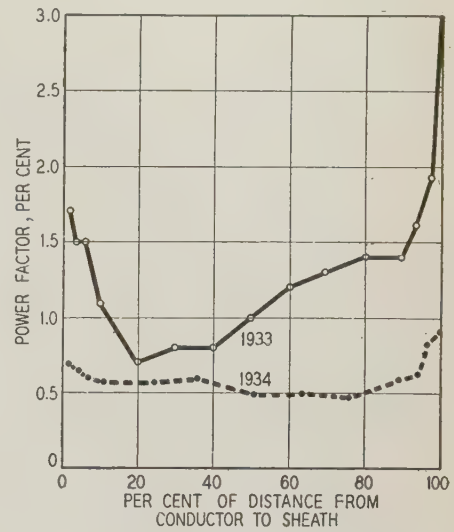
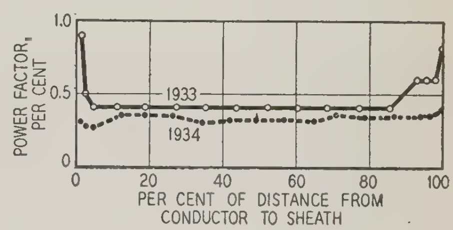


Fig. 5. Effect of modified manufacturing methods on the radial characteristics of brand A cable



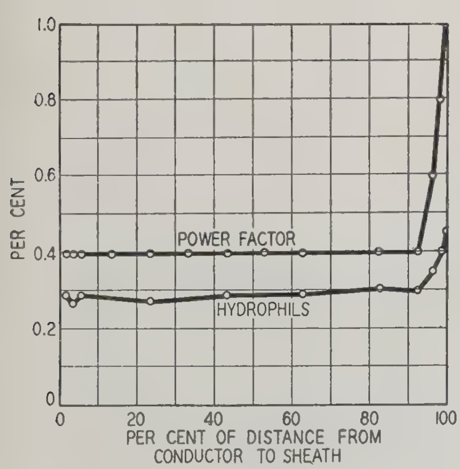


Fig. 3. General correspondence of radial hydrophil and power factor values

Power factor measured at 60 degrees centigrade and 50 volts per mil

Practical Results of the Radial Method

Measurement of the radial characteristics of cable insulation has proved useful to the enterprising cable manufacturer in improving quality. During the past year, the manufacturer of brand *F*, figure 2, which

had the least desirable radial characteristics of the 6 brands tested, has greatly improved his methods and technique. The radial power factor curve of his most recent product is shown in figure 4, in order to permit more ready comparison the curve F (1933 product) of figure 2 has been replotted in this figure.

Even the best product may be improved when a means is available for detecting flaws. The manufacturer represented by brand A in figure 2 desired to eliminate the upturns of the radial power factor curve. The results of his efforts may be judged by comparing the radial power factor curve for 1934 cable with that of 1933 cable of the same brand (figure 5). It may be seen that a distinct improvement has been effected by the known improvements in the process.

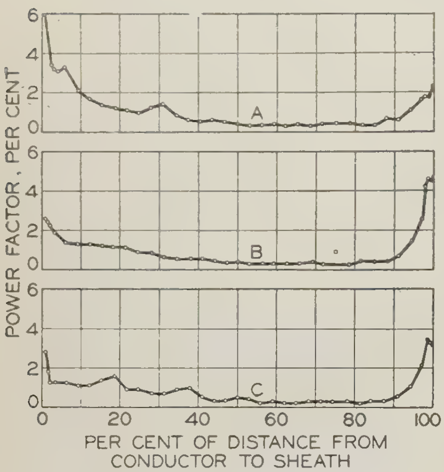


Fig. 6. Radial power factor of 3 sections from a 64 foot length of single conductor extra - high - voltage cable, measured at 60 degrees centigrade and 50 volts per mil

General improvement in all brands of cable should follow a study of the effect on the radial characteristics of the finished cable of the more rigid control of each step in manufacture. Apparatus for measuring radial power factor has been built by practically all the manufacturers represented in figure 2 and by several power companies active in cable research.

Reliability of Measurement of Power Factor of Individual Paper Tapes

The question frequently has been raised as to whether the power factors of the individual layers of the cable give a reliable indication of the power factor of the cable measured as a whole.[4] An opportunity to answer this question presented itself when a 64 foot length of used single-conductor high-voltage cable, the over-all power factor of which carefully had been measured in a hot box, was submitted for radial examination. Six sections, each 18 inches long were removed from the 64 foot length, one from each of the ends and the remaining 4 at equal intervals. One section was removed at a time; radial power factor measurements were made immediately following removal and preparation of samples. Extra precautions were taken in the preparation to prevent contamination from exposure of the ends of the cable to the atmosphere.

The radial power factors of 3 representative sections are shown in figure 6. In calculating the power factor of the cable it would not be correct to average the areas under the 6 radial power factor curves since a high loss tape at the conductor obviously would not affect the total power factor as much as a high loss tape at the sheath, because of volume considerations.

Taking due account of the volume considerations, the power factor of the cable may be calculated with close approximation from the formula

$$P_t = \frac{\int_a^b \frac{P_n dr}{r}}{\log \frac{b}{a}}$$

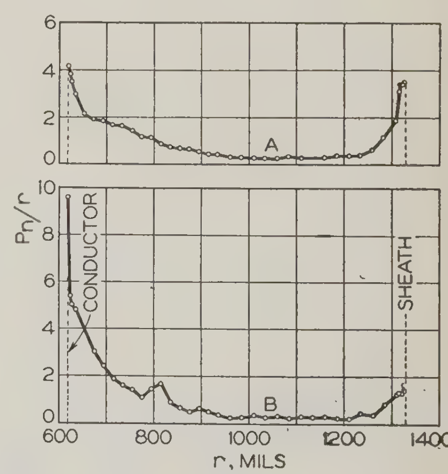
where

P_t = power factor of the cable
P_n = power factor of individual tape n at radius r
r = radius at which tape n is located
a = radius of the conductor of the cable
b = radius of the outer layer of the insulation

In a cable the stress throughout the insulation varies whereas in the tape power factor cell the stress is maintained constant for each layer. This would have considerable bearing on the correctness of this method were it not true that the power factor of impregnated paper insulation that is not badly deteriorated does not vary greatly with stress below the ionization point.

The values P_n/r in the formula were plotted against r for each of the 6 sections; r varied between 620 and 1,340 mils. Representative curves for 2 of the sections are shown in figure 7. The power factor of each section was determined by graphical integration and division by log (b/a) and the 6 power factors averaged. The average of these 6 values was considered as the power factor P_t of the cable.

Fig. 7. Plots for 2 sections of cable of P_n/r versus r used for graphical integration in obtaining the total power factor from power factors of individual paper tapes



This average value was 0.82 per cent. Measurements as indicated in figure 6 were made at 60 degrees centigrade and 50 volts per mil. The power factor of the cable as measured in a hot box was 0.75 per cent at 60 degrees centigrade and 28 volts per mil. In the 2 tests the temperatures were equal, but there was some difference in the measuring stress. Because of the fact that the power factor-voltage characteristics of impregnated paper are

slightly rising, the agreement would have been even closer had the measuring stress been the same.

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Adequate Lighting Is a Sound Investment

A number of examples in which an increased intensity of illumination in industrial establishments resulted in an actual increase in production are cited in this paper. Other results also attributed to adequate lighting are that better work can be done, accidents are reduced, and waste space may be made available for production.

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BECAUSE better illumination does cut costs, increase efficiency, reduce accidents, and establish better working conditions, lighting in industrial plants everywhere will probably be revolutionized in the next few years. At present industrial lighting averages less than 5 foot candles, one survey of 2,000 industrial plants even averaging below 3, as compared with the safe minimum of 10 foot candles. Industry is awakening to advantages of better lighting as a result of recent developments in lighting and of many industrial lighting surveys. The following are only a few examples of many instances where proper illumination definitely increased production.

ADEQUATE LIGHTING INCREASES PRODUCTION

One of the most conclusive proofs that good lighting pays its cost is furnished by a national piston company. This plant was inadequately lighted and the local power company induced them to make a lighting test. The president reports that at the beginning of the test the plant was running at about 70 per cent capacity with a lighting intensity of 1.2 foot candles. In one department the lighting was stepped up to 6.5 foot candles and production increased 13 per cent. Then it was further increased to 9 foot candles and an additional 4.9 per cent increase was obtained. Finally the lighting was increased to 14 foot candles and production jumped another 6.9 per cent. In all, the lighting of 14 foot candle intensity increased production 25.8 per cent over the old installation.

In the inspection department of a large roller bearing manufacturer a thorough test of the effectiveness of light in increased production was made. The original system of lighting provided 5 foot candles at the inspection table. The number of pieces inspected per hour per operator was 408. When the new lighting installation providing 20 foot candles was in operation, production jumped to 458 pieces per hour per operator—an increase of 12.5 per cent. This intensity was maintained for 2 weeks, then decreased to 13 foot candles, and immediately production dropped to 440 pieces per hour per operator. When it was later set back to 20 foot candles production increased to its peak.

In a hosiery plant proper illumination was installed and immediately production of knitting machines jumped 10.8 per cent and of looping machines 6.1 per cent. The cost of the installation was only 0.4 per cent and the operating cost 0.1 per cent of the yearly pay roll.

In the composing room of a large register company the lighting was old-fashioned, inadequate, and spotty. Men at work setting type were slow and errors were frequent. The management consulted a lighting specialist and he recommended an entirely new system with modern equipment and mazda lamps of proper size. After the new installation was made a careful check was kept; production increased 6 per cent and only 20 cents per day was added to the light bill.

In a plant operating a battery of wire drawing machines a haphazard system of drop cord lighting was replaced with a scientifically planned overhead system. Immediately the output of the machines was increased 21 per cent.

A manufacturer of automobile parts reports that after installing a new lighting system which increased lighting intensity 133 per cent, labor turnover dropped from 6.37 per cent per month to 2.78 per cent per month. In addition, work was speeded up enough to pay for the complete installation in 18 months.

ADEQUATE LIGHTING AIDED BY MANY FACTORS

The development of the light meter, which is a portable compact means of measuring lighting intensities, makes it possible to check easily and

Full text of a paper recommended for publication by the A.I.E.E. committee on production and application of light. Manuscript submitted Aug. 15, 1934; released for publication Aug. 22, 1934.

accurately the intensity of light provided by artificial illumination in industrial plants everywhere. Illumination research laboratories have discovered by actual test that wherever eyes are used for work that 10 foot candles is an absolute minimum. Further tests have also revealed that working under intensities less than 10 foot candles causes not only severe eye strain but results in fatigue, sleepiness, nervousness, headaches, indigestion, etc. Glare from light sources in the line of vision, reflections from glossy surfaces, and uneven distribution of light are also features which contribute to this condition.

As a general premise to a new lighting approach to industry, 3 definite recommendations are being made: (1) Increase intensities; (2) abolish glare; and (3) provide uniform distribution.

Adequate lighting is a working tool in any plant. The importance is best summed up in an adaptation of a well-known adage "As a man sees, so does he work."

Industry has spent tens of thousands of dollars in developing machines of greater efficiency, but the most delicate machine is not half as sensitive as the operator. And when conditions are such that it is difficult to see, when surroundings are dark and gloomy, operators cannot be expected to get the most out of machines. Production suffers. Costs increase. Accidents increase.

Other important considerations are the new industrial codes under which industry is working. Shorter work days and shorter work weeks have necessitated the addition of more shifts and the employment of more men. Better illumination enables employers to get a greater volume of work and greater securacy from each employee under the shorter hours and perhaps increased pay.

Better Work and Reduction in Accidents Result

But not only does better lighting mean increased production, it also means better work. Employees can see better, but equally important they have a more inviting, improved working condition and plant atmosphere. A dark, gloomy plant is depressing to workers and they cannot be expected to do their best in surroundings of this character. Better light will increase the morale of the entire staff to a pitch which assures good work and high efficiency. Also, workers are more dependable in well-lighted plants, and more satisfied to stay on the job—therefore, labor turnover is substantially reduced.

Improved lighting also means decreased accidents. Workmen who can see danger rather than merely sense it are less likely to be involved in accidents. And accidents in addition to their regrettable nature cost industries large sums of money year after year.

One of the most interesting descriptions of the relationship between lighting and accidents is found in the code of lighting prepared under the direction of the Illuminating Engineering Society. This report points out that the National Safety Council estimates that the number of fatalities in the United States arising out of or in the course of gainful employment was 24,000 for the year 1928, and that during the same period the lost time nonfatal accidents reached the staggering total of 3,125,000. The report also points out that a prominent insurance company shows justification for assuming that defective vision and deficient or unsatisfactory lighting installations are contributing factors of 18 per cent of these accidents. This means that from these causes industries are being deprived of the equivalent of the services of 35,000 men throughout each entire year due to lost time nonfatal accidents. This is indeed a high price to pay for neglect of light and vision.

Quoting further from this report it is discovered how from a dollars and cents standpoint accidents cause industry thousands of dollars a year.

"Compensation insurance premiums for a plant are based on the amount of the pay roll, and the rate is determined by the accident experience of a given industry, modified by the experience of a particular plant under consideration. With a rate of 1.5 per cent the annual premium in the case of 1,000 employees at an average wage of $40 per week would be $31,200.

"An insurance carrier might, at an average, pay the claims resulting from 4 accidents per month in this plant, and meet its own overhead cost, and still have slight margin of profit. An experience of 5 accidents per month, $^{1}/_{5}$ of them due to improper lighting (a not unlikely event) would probably leave the insurance carrier no option but to increase the rate by 25 per cent. This premium would then be $39,000, an increase of $7,800. If poor lighting costs only $3 per employee or $3,000 per year total, the owner's annual expense for poor illumination actually amounts to $10,800, of which $7,800 is required by the insurance company to meet additional accident claims. An expenditure of $6 to $8 per year per employee for more adequate illumination might save a large portion, if not all, of the latter amount. The important point here is the fact that the cost of accidents, due to poor illumination, greatly exceeds the cost of providing adequate illumination."

Waste Space Made Available for Production

Another important advantage of modern lighting in industry is that it makes all space available for active production. With spotty and inadequate illumination there is a large percentage of modern plant floor area which is dark and useless for actual production. The machinery and production line must be grouped close to existing lighting units, leaving large areas which are useful only for storage purposes, et cetera. These areas can be transformed immediately through installation of modern lighting to useful productive activity. Machinery can be arranged for efficient production, and in many cases more machinery and men can be employed in a given plant area. Also, in a plant where dark corners and out-of-the-way spots exist, there exists the opportunity for workmen to seek these spots for idle, unproductive moments.

From the foregoing facts it is readily evident why industry is taking a definite step toward revolutionizing industrial lighting standards.

The lighting industry for years has had the equipment to make possible illumination as now recommended. But it has only been recently that any one has fully appreciated the intimate relationship between light and sight and human efficiency. Now that the facts are known, and that electrical manufacturers are taking steps toward disseminating this knowledge, it will be interesting to observe how quick industry will be in establishing the new standards as recommended.

Probability in Engineering

The value of probability theory in the field of engineering is forcefully brought out in this paper, which explains the fundamentals of the theory, not by the use of mathematics, but by the solution of sample problems of types frequently encountered.

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THE purpose of this paper is to emphasize the practical value of probability theory in engineering. Since engineering problems are of a quantitative character the paper relates to the mathematical aspect of the theory. But the reader will not be burdened with a lot of mathematics; for the purpose of this paper a few comments on the theory itself, followed by the presentation of the solution of some problems, will suffice.

What is probability? The greatest authority on the subject, Laplace, wrote that "the theory of probability is, fundamentally, nothing but good sense reduced to calculation."

Note carefully the qualification "reduced to calculation." Good, or common, sense so reduced does not subscribe, for example, to the placing of odds in favor of tail in the ninth throw if the first 8 throws of a penny gave head every time.

Essentially full text of a paper presented at a meeting of the Sharon (Pa.) Section of the A.I.E.E., April 9, 1934, and at a joint meeting of the Pittsburgh (Pa.) Section of the A.I.E.E. and the electrical section of the Engineer's Society of Western Pennsylvania, April 10, 1934; and recommended for publication by the A.I.E.E. committee on communication. Manuscript submitted April 20, 1934; released for publication August 1, 1934.

EDITOR'S NOTE: Those interested in the subject of probability from the point of view of engineering application may wish to read Albert A. Bennett's article ("Theory of Probability," ELEC. ENGG., v. 52, 1933, p. 752–7) which was the first article of the special "Science Series for Engineers" sponsored by the A.I.E.E. committee on education.

The "reduction to calculation" was inaugurated in 1654 when a notorious gambler, the Chevalier de Méré, submitted to the mathematician Pascal a problem of chances involving dice. Pascal and his friend Fermat then started a voluminous correspondence in which they embodied the elementary principles of the theory. During the following $2^1/_2$ centuries such famous mathematicians as James Bernoulli, DeMoivre, Laplace, Poisson, Gauss, DeMorgan, Boole, Bertrand and Poincaré contributed their share to the "reduction" with the result that today the mathematical theory of probability constitutes a body of principles which transforms into an exact science the rule of thumb methods previously used in the handling of certain broad classes of problems. The chief characteristic of these problems is that they involve mass phenomena where law and order reign in the aggregate in spite of apparent chaos in the individual.

From both the theoretical and practical points of view the domain of probability splits into 2 main divisions known as the *a priori* and the *a posteriori*. Two simple problems, one *a priori*, the other *a posteriori*, quoted from the "theory of sampling" will serve as definitions of these terms.

a priori: A box contains 1,000 relays. It is known that 50 of them are defective. If 100 of them are selected at random what is the probability that, say, 10 of the 100 selected will be defective?

a posteriori: A box contained 1,000 relays of which some unknown number were defective. Of 100 relays selected at random from the box, 10 were defective. What is the probability that, say, 50 of the 1,000 relays were defective?

In the first case a universe with *known* characteristics is given and a probability question is asked regarding a sample which is to be taken from the universe. In the second case the characteristics are given of a sample which has been taken and a probability question is asked regarding the *unknown* sampled universe.

So much for the theory of probability as such and its 2 logical divisions. Let some applications be considered.

Three problems will be presented from the domain of engineering with which the writer is most familiar, telephony. However, their probability aspects are shared by other fields of engineering and moreover details and qualifications, which are of interest only to the telephone engineer, will be omitted.

The first and second problems belong in the *a priori* division of probability theory, but it is not essential to bear this in mind. At the end of the discussion of the third problem, some comments will be made on an aspect of *a posteriori* problems which, if overlooked, may lead one to quite erroneous conclusions as to the significance of a sample from an unknown universe.

I—Application to a "Trunking" Problem

The engineer responsible for the amounts of equipment which should be installed for the giving of adequate service at a fair price is confronted with the following question: Knowing the average demands which will be made for a certain service,

what are the probabilities for or against various fluctuations in excess of the anticipated average demands?

As an example consider, in a general way, what is technically known as a "trunking" problem.

Imagine a telephone exchange serving 2,000 subscribers; call this exchange A. To simplify the

Fig. 1. Simple telephone exchange system

discussion assume that all outgoing calls from A are made for subscribers in a nearby exchange which will be referred to as exchange B. (See Fig. 1.)

Shall 2,000 interoffice trunk lines be installed so that the entire 2,000 subscribers of A may talk simultaneously with their friends of exchange B? Of course not; in the first place, not once in a century would all the subscribers wish to talk simultaneously unless an earthquake or some such catastrophe were to occur; in the second place, the cost would be intolerable. A more rational and practical point of departure would be to assume that, under normal conditions, only one out of every 100 calls shall fail to find immediately an idle trunk line at its disposal.

Suppose that during the busy hour of the day each of the 2,000 subscribers of exchange A makes a call for B and, moreover, that when a connection is established between the 2 exchanges the conversation lasts for exactly 2 min. Since 2 min. is $^1/_{30}$ of the hour, it is anticipated that *on the average* $^1/_{30}$ of 2,000 = 66.7, say 67, simultaneous conversations must be provided for. But what about deviations from the average; more particularly, what are the probabilities that the average number will be exceeded to various extents? To answer this question examine Table I. This table is based on the Poisson probability or "frequency" law which gives

$$a^x e^{-a}/x!$$

as the probability that an event will happen *exactly* x times if on the average it happens a times. The corresponding probability that the event will happen *at least*, say c times, is

$$\sum_{x=c}^{x=\infty} a^x e^{-a}/x!$$

In these formulas e represents the number 2.7182 . . . which is the base of natural or hyperbolic logarithms.

Although the number of conceivable laws relating average results to deviations therefrom is legion, the Poisson law is one which has a great range of applications in physics, biology, engineering, and elsewhere. Its application to the telephone problem under consideration is justified both on theoretical grounds and by the results of numerous observations.

To determine the number of trunk lines which should be installed to meet the 1 in 100 condition, read down column III of the table until a probability of 0.01, or the nearest value thereto, is encountered. Then reading across to the corresponding entry in column I the number 87 is found. Thus, finally, 87 interoffice trunk lines must be installed when the average number of conversations expected is 67.

In order to emphasize the utility and significance of tables such as Table I and Table II, also based upon the Poisson law, the trunking problem will be carried a step further.

Manual or automatic means are required in order that any one of the 2,000 subscribers shall have access to all of the 87 outgoing trunks. The mechanics of this part of the problem would be simpler and perhaps cheaper if the subscribers were divided into 2 groups of 1,000 each and then 2 separate groups of trunks running from exchange A to exchange B were installed. To what extent will this arrangement, if put into effect, increase or decrease the total number of trunks? Consider the following analysis.

On the assumptions made above each group of 1,000 subscribers will contribute on the average 66.7/2 = 33.4 simultaneous conversations. When the average is 33.4, Table II tells us that 48 trunks are required to give a 1 in 100 grade of service. Therefore, it will be necessary to install 48 trunks *per group* of 1,000 subscribers or a total of 2 × 48 = 96 trunks. This is an excess of 96 − 87 = 9 trunks over the number required when it is feasible to serve the subscribers as a single group of 2,000.

The reader will appreciate without further analysis that the theory of probability, together with a knowledge of unit cost figures and other factors which the telephone engineer must take under consideration, enables him to determine the optimum division of subscribers into subgroups.

A problem of the type which has been under discussion here and is of special interest to the power engineer forms the subject matter of the paper entitled "Spare Capacity Fixed by Probabilities of

Table I—Probability Table

Possible Number of Simultaneous Conversations	Probability That Number of Simultaneous Conversations Will Be: Exactly That Specified in Column I	At Least That Specified in Column I
I	II	III
65 = 67 − 2	0.047952	0.612877
66 = 67 − 1	0.048678	0.564925
67 = average	0.048678	0.516246
68 = 67 + 1	0.047962	0.467567
69 = 67 + 2	0.046572	0.419606
80 = 67 + 13	0.013600	0.066446
85 = 67 + 18	0.004665	0.019069
86 = 67 + 19	0.003634	0.014404
87 = 67 + 20	0.002799	0.010770
88 = 67 + 21	0.002131	0.007971
106 = 67 + 39	0.000003	0.000006

Outage" by S. A. Smith, Jr. (*Elec. World*, v. 103, 1934, p. 222–5). In the opening paragraph the author says:

"In the engineering of power systems one of the most important objects is the attainment of a high degree of continuity of service. In attempting to achieve this many millions of dollars are spent for reserve equipment and protective devices. Seldom, however, is the proper degree of service reliability known or defined in quantitative terms, and rarely does the designer employ a truly rational method to attain it. Some way of defining the goal must be found and some scientific means of reaching it sought."

Mr. Smith then proceeds to outline how probability theory supplies a "scientific means" of arriving at results.

II—Application to a Problem in Recurrent Structures

An extensive class of probability problems arises from the recurrent or periodic structure of certain kinds of equipment. In long telephone circuits, for example, such a structure results from "transpositions" in the pair of wires of a talking circuit in order to eliminate crosstalk between adjacent pairs. Another example is circuits wherein "repeaters" for amplifying the voice currents are inserted at several points along the line. (See Fig. 2.)

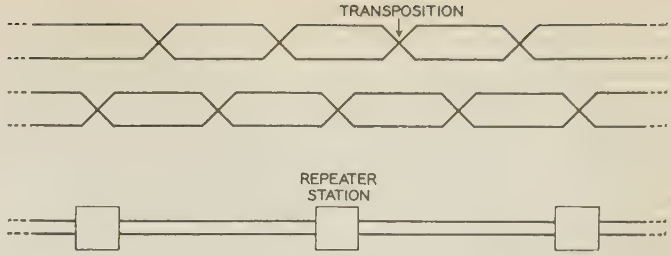

Fig. 2. Engineering examples of recurrent structures

Now in any recurrent structure one is confronted with irregularities; no 2 transposed sections are exactly alike in length or in the distance between adjacent pairs, no 2 repeaters are exactly alike in their electrical characteristics or there may be slight variations in the voltages of the local batteries which supply them with current.

The central question in this class of problems is: What is the probability that the *cumulative* effect, or sum, of several relatively small independent irregularities will lie within a specified range? It is to be understood that each individual irregularity is likely to have any one of a finite number, or of an infinite number, of possible values.

One may venture to state that every field of engineering is saturated with problems of the type now under consideration. Of course, the saturation point may be much lower in some fields than in others.

Consider the line equipped with repeaters, limiting the discussion to the irregularities resulting from slight variations in the voltage of the local batteries installed at each repeater station. Assume that each repeater gives a nominal gain, or amplification, of say 30 db (decibels). For the purpose of this paper the precise meaning of the term decibel is not essential; it suffices to bear in mind that it is a convenient unit for measuring power gains or losses in transmission.

An irregularity or departure on the part of an individual repeater from the nominal value of the gain expected from it will, of course, react on the total transmission gain to be expected from the several repeaters collectively. The problem confronting the telephone engineer is, then, to find the probability

Table II—Averages Corresponding to Average Plus Deviation to Be Expected With Different Probabilities

Average plus Deviation	Probabilities										Average plus Deviation
	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	
c	Average a										c
1	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	1
2	0.045	0.065	0.080	0.092	0.104	0.114	0.124	0.133	0.141	0.149	2
3	0.191	0.243	0.281	0.312	0.338	0.361	0.382	0.402	0.419	0.436	3
4	0.429	0.518	0.581	0.630	0.672	0.709	0.741	0.771	0.798	0.823	4
5	0.739	0.872	0.954	1.02	1.08	1.13	1.17	1.21	1.25	1.28	5
6	1.11	1.27	1.38	1.47	1.54	1.60	1.65	1.70	1.74	1.79	6
7	1.52	1.72	1.85	1.95	2.04	2.11	2.17	2.23	2.28	2.33	7
8	1.97	2.20	2.36	2.47	2.57	2.65	2.73	2.79	2.85	2.91	8
9	2.45	2.72	2.89	3.02	3.13	3.22	3.31	3.38	3.45	3.51	9
10	2.96	3.26	3.45	3.60	3.72	3.82	3.91	3.99	4.06	4.13	10
12	4.04	4.40	4.63	4.80	4.94	5.06	5.17	5.26	5.35	5.43	12
14	5.20	5.61	5.87	6.07	6.23	6.37	6.49	6.60	6.69	6.78	14
16	6.41	6.87	7.16	7.39	7.57	7.72	7.86	7.97	8.08	8.18	16
18	7.66	8.17	8.50	8.75	8.94	9.11	9.26	9.39	9.51	9.62	18
20	8.96	9.52	9.87	10.14	10.35	10.54	10.70	10.84	10.97	11.08	20
22	10.29	10.89	11.27	11.56	11.79	11.99	12.16	12.31	12.45	12.57	22
24	11.65	12.29	12.70	13.01	13.26	13.47	13.65	13.81	13.96	14.09	24
26	13.03	13.72	14.15	14.48	14.74	14.96	15.16	15.33	15.48	15.62	26
28	14.44	15.17	15.63	15.97	16.24	16.48	16.68	16.86	17.03	17.18	28
30	15.87	16.64	17.12	17.48	17.77	18.01	18.23	18.42	18.59	18.74	30
32	17.32	18.12	18.62	19.00	19.31	19.56	19.79	19.98	20.16	20.32	32
34	18.78	19.62	20.15	20.54	20.86	21.13	21.36	21.57	21.75	21.92	34
36	20.26	21.13	21.68	22.09	22.42	22.70	22.94	23.16	23.35	23.53	36
38	21.76	22.66	23.23	23.66	24.00	24.29	24.54	24.76	24.96	25.14	38
40	23.25	24.20	24.79	25.23	25.59	25.89	26.14	26.38	26.58	26.77	40
42	24.78	25.75	26.36	26.82	27.19	27.49	27.76	28.00	28.21	28.41	42
44	26.30	27.31	27.95	28.41	28.79	29.11	29.39	29.63	29.85	30.05	44
46	27.85	28.89	29.54	30.02	30.41	30.74	31.02	31.27	31.50	31.71	46
48	29.40	30.47	31.14	31.63	32.03	32.37	32.66	32.92	33.15	33.37	48
50	30.96	32.06	32.74	33.25	33.67	34.01	34.31	34.58	34.82	35.03	50

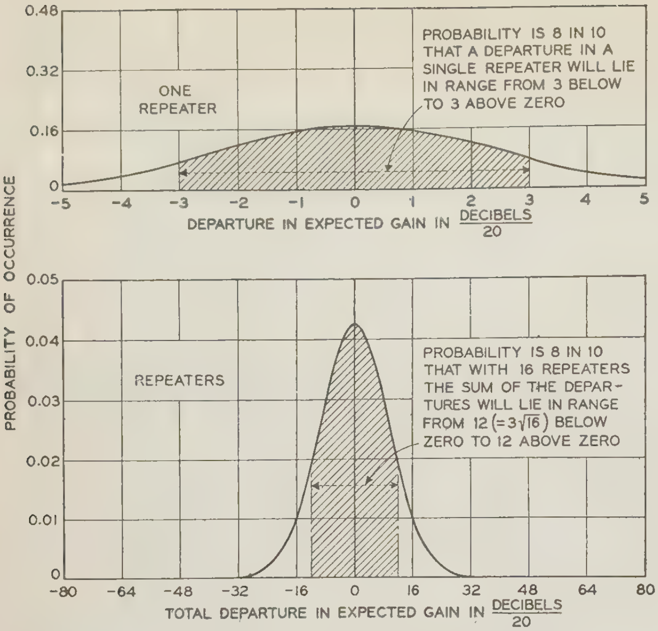

Fig. 3. Gain fluctuation in line equipped with repeaters

or chance that the total gain of a number of repeaters will depart from the total nominal gain (for that number of repeaters) by an amount equal to or less than a specified amount.

In the solution of the problem the first question to be answered is: What are the possible values for the departure at an individual repeater and what is the probability in favor of each value, or infinitesimal range of values? This question is usually answered by an appeal to existing records of the past behavior of individual repeaters.

Let us assume, then, that the information embodied in the upper curve of Fig. 3 is given.

The abscissa x of a point on the curve represents a possible value for the departure, the unit departure being 0.05 db, for example; the ordinate y represents the relative probability in favor of the occurrence of the departure of magnitude x. Moreover, assume that the equation to this curve is

$$y = \frac{1}{\sigma_1\sqrt{2\pi}} e^{-X^2/2\sigma_1^2}$$

with, for example

$$\sigma_1 = 2.34$$

This is another outstanding law relating average, or mean, values to departures therefrom. In Fig. 3 the mean value is represented by the origin 0 of abscissas. The constant σ_1 conventionally known as the "standard deviation" determines the slope of the curve and is a measure of the extent to which the departures tend to cluster around the most probable value. Many readers of this paper will recognize the law, although it has changed its name several times; Normal, DeMoivre, Gaussian, Laplace-Gaussian are among those under which it travels.

Now, when the individual departure obeys a Normal law, the mathematical theory of probability shows that the sum of n departures likewise obeys a Normal law, but with a standard deviation, $\sigma_n = \sigma_1\sqrt{n}$. (This relation between standard deviations holds even when the individual and cumulative departures do not obey normal laws.) Write

$$X = x_1 + x_2 + x_3 + \ldots x_n$$

for the sum of the n individual departures. There then results

$$\frac{1}{(\sigma_1\sqrt{n})\sqrt{2\pi}} e^{-X^2/2(n\sigma_1^2)}\, dX$$

for the probability in favor of the occurrence of a sum whose value lies in the infinitesimal range $X \pm \frac{dX}{2}$, and

$$\frac{2}{(\sigma_1\sqrt{n})\sqrt{2\pi}} \int_0^{X'} e^{-X^2/2(n\sigma_1^2)}\, dX$$

for the probability that the total gain given by n repeaters will lie within the range X' on either side of n times 30 db.

There can now be stated in general terms a conclusion of great practical importance which results from the theory of probability: As consideration is transferred from a line equipped with a number, say n, of repeaters to a line equipped with a larger number, say N, *the range of values for which there is a specified probability that the sum of the departures from normal gain will lie therein*, instead of increasing in the ratio of N to n, increases only as the square root of this ratio.

In the lower half of Fig. 3 the outcome is observed for a line equipped with 16 repeaters, the "standard deviation," for each individual irregularity being $\sigma_1 = 2.34$, as assumed above.

III—Application to a Problem of the *A Posteriori* Type

The 2 telephone problems which have been considered belong to the *a priori* domain of probability theory. The *a posteriori* domain will now be en-

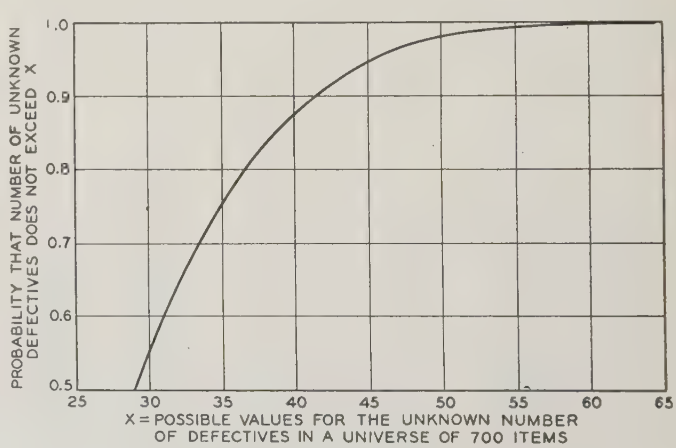

Fig. 4. Curve showing probability that the unknown per cent of defectives in a universe of 700 items does not exceed a specified value, it being known that a sample of 200 out of the 700 contained 4 per cent defectives

tered. The importance in engineering of this aspect of the mathematical theory of probability will be emphasized by a brief analysis of a "sampling" problem.

It is necessary to distinguish between the sampling of "attributes" and the sampling of "variables" since they involve different techniques. The sampling of "attributes" relates to problems where each individual of the universe sampled has or has not a specified characteristic; the case of "variables" arises when it is asked *to what extent* each item of the universe possesses a certain character.

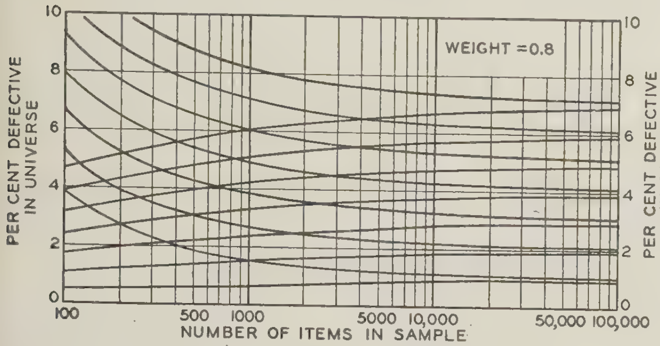

Fig. 5. Curves showing, for an infinite universe and with a weight or surety of 8 in 10, the range within which lies the per cent of defectives in the universe for various sizes of sample and various per cent defectives in the sample

The figures at the right are the designations (in whole numbers) of each pair of curves which tend to converge at the right. The ordinate scale is on the left

A typical sampling of "attributes" problem is the following: Suppose a shop has received a shipment of 700 triode tubes. Assume that a test of 200 of these tubes, selected at random, disclosed that 4 per cent of them had broken filaments. What inference does this disclosure justify as to the per cent of triodes with broken filaments in the entire lot of 700? For example, what is the probability that it is not greater than 5 per cent; that it is not greater than 6 per cent?

These and equivalent questions can be readily answered by reference to the curve in Fig. 4. The abscissas indicate possible values for the number of triodes with broken filaments in the universe of 700; the ordinates give the probabilities that the unknown number of defectives does not exceed the values indicated by the abscissas.

To answer these questions proceed as follows: 5 per cent of 700 is 35; the point on the curve whose abscissa is 35 has 0.75 for its ordinate. Therefore, it is inferred that the probability is 75 in 100 that not more than 5 per cent of the 700 triodes are defective. Likewise, since 6 per cent of 700 is 42, a probability is inferred of 91 in 100 that the defectives do not exceed 6 per cent of the total number of tubes.

If the number of individuals in the universe is very large compared with the number sampled, the inferences which can be drawn from the characteristics of the items sampled are, approximately, independent of the size of the universe. Therefore, the next step is to go the limit and assume that the sample of 200 triodes containing 4 per cent defectives was obtained by selections at random from an *infinite* universe. In this situation pairs of curves, such as those in Fig. 5, are very useful. Each pair of curves corresponds to a specified per cent of defectives in the sample; this per cent is indicated at the extreme right end where a pair converges together. The sample sizes are indicated by the abscissas plotted on a logarithmic scale. The ordinate scale on the left relates to the unknown per cent defectives in the infinite universe from which the sample was taken.

Next, find the abscissa corresponding to the sample of 200 triodes. Then follow the vertical line above this abscissa to where it crosses the pair of curves converging toward the value 4 at the right. The ordinate of the crossing with the lower curve reads 2.7 on the scale to the left, with the upper curve its value is 6.5. Now the caption to all the curves reads "Weight 0.8." Therefore, it is inferred that:

a. The probability is 8 in 10 that the true unknown per cent defectives, in the infinite universe of triodes, lies in the range 2.7 to 6.5.

b. The probability is 1 in 10 that it *exceeds* 6.5; likewise, the probability is 1 in 10 that it is *below* 2.7.

In drawing inferences as to the number of defectives in the shipment of 700 triodes, no consideration has yet been given to any available information on the character of the shipment other than that obtained from the sample of 200 tubes. For example the fact has been ignored that the shipment came from, say, one or the other of 2 manufactories, one having a well established reputation for reliability in its product, the other being a relatively new concern. The probabilities assignable from this information to the various possible values for the unknown per cent of defectives in the shipment must be taken into account in conjunction with the probabilities based upon the outcome of the sample. The former probabilities are called in the literature *a priori existence probabilities* because they relate to information existing before the sample is drawn although it need not be taken into account until later.

The curves shown in Fig. 4 and 5 are based upon the assumption that the *a priori existence probabilities* are all equal or, in nontechnical words, that all the possible values for the number of defectives in the universe were equally likely before the sample was taken. Such an assumption can be made without serious consequences when the number of items sampled is large, because the implications of a large sample will outweigh to a great extent any prior information about the character of the universe.

In closing this discussion of sampling theory the writer would express an opinion which is certainly justified on theoretical grounds though not, as yet, on sad experience: It is that when circumstances are such that inferences must be drawn from a *small* sample, one should consult an expert in probability theory and, in doing so, make sure that there is no misunderstanding with him as to just what inferences are under consideration.

Lubrication Increases Life of Meter Bearings

Recent research reported in this paper shows that lubrication of pivot bearings of electric watthour meters is essential for maximum bearing life. The performance of these bearings represents the most important mechanical factor in sustained meter accuracy. The comparatively high rate of wear in a new bearing is found to decrease rapidly with use, finally becoming extremely small. With a well lubricated bearing, the effect of the increased friction resulting from wear on the calibration of the meter is shown to be negligible. A jewel screw of new design, having a large oil reservoir to provide for proper lubrication over a long period of time, also is described.

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ATTAINMENT of sustained accuracy always has been the most important problem in the manufacture and use of electric watthour meters. With the modern tendency toward longer intervals between periodic tests, a review of the factors affecting this problem is pertinent.

Electrically, the accuracy of the meter is dependent upon the permanence of the damping magnets and the permanence of the mechanical positioning of the parts of the electric and magnetic circuits. The use of properly treated and processed high strength magnets has reduced the first factor to one that is unaffected by time. Careful design and manufacture made possible by years of experience have practically eliminated the changes resulting from mechanical shifting of the parts of the meter.

The parts that now need to be carefully considered, are those subject to mechanical change resulting from wear. Most of the parts of the meter operate at such slow speeds and low pressures that the slight wear is not of sufficient magnitude to affect the accuracy of the meter even over extremely long periods of time. The lower bearing, however, operates at a very high pressure and, although the linear speed is low, serious wear may take place if the conditions are not controlled properly. The lower bearing becomes, therefore, the most important mechanical factor in sustained meter accuracy and is the subject of the research reported in this paper.

A paper recommended for publication by the A.I.E.E. committee on instruments and measurements and scheduled for discussion at the A.I.E.E. summer convention Ithaca, N. Y., June 24–28, 1935. Manuscript submitted Jan. 7, 1935; released for publication Feb. 27, 1935.

From the results of the work done, the following conclusions have been drawn:

1. A well lubricated pivot bearing has many times the useful life of a poorly lubricated or dry one.
2. Under normal conditions the amount of wear of a well lubricated bearing, as indicated by the worn area on the end of the pivot, tends to approach a constant value.
3. The amount of wear of the well lubricated bearings tested was not sufficient to result in any appreciable decrease in meter accuracy.
4. A special type of jewel screw is necessary to provide good lubrication, and hence sustained accuracy, over long periods of time.

Obtaining Data on Bearing Performance

Three methods of obtaining data on bearing performance are:

1. Field tests made under actual service conditions.
2. Normal speed tests made in the laboratory under controlled conditions.
3. Accelerated tests made in the laboratory and devised to give results within a short time that would require years of operation in normal service.

A considerable amount of information on the long time performance of bearings under certain specific conditions was available from both field and laboratory tests made over several years. Certain things were indicated by these data that it was important to test out within a reasonably short time. The following accelerated life test was set up for this purpose.

A 5-ampere 115-volt standard-type watthour meter operating at 100 per cent load rotates at the rate of 15.97 rpm. The damping magnets were removed so that the speed increased to about 30 times normal. If the bearing be considered as a power consuming device in which work is done in overcoming friction and wear be assumed to be proportional to the work done, then as much energy must be dissipated per revolution at the accelerated speed as at normal operating speed if the same wear is to be obtained under both conditions. However, as the coefficient of friction is known to decrease somewhat with velocity, other conditions remaining the same, less energy is dissipated per revolution at the higher speeds. This decrease in friction coefficient can be compensated by increasing the weight of the disk; accordingly, as it was desirable to make the wear per revolution at the high speed greater than under normal operating conditions, the 13.2 gram standard rotor was replaced by a special rotor weighing 75 grams. A tremendous increase in the bearing pressure was thus obtained, which added materially to the severity of the test.

To simulate service conditions it was desirable to run the test meters on an intermittent load cycle. A time switch therefore was connected in series with the load and set to give an operating cycle of $3^1/_2$

minutes *on* and $^1/_2$ minute *off*. The potential circuit was connected at all times, and the potential flux was sufficient to damp the rotating element practically to rest during this $^1/_2$ minute *off* period.

Consideration was given to the effect of the higher speeds on the lubricating problem, but calculations showed the speed of a point on the contact circle to be so low that even at the speed of approximately 500 rpm the linear velocity of a point on the outer edge of the circle of contact for a new bearing was only 0.730 inch per minute. With so low a speed it is evident that the lubrication conditions cannot be affected materially by the inertia forces resulting from the increase in speed.

Bearing Wear as a Function of Lubrication

Accelerated tests were made to determine the relationship between the rate of wear and the lubrication of the bearing. Three fundamentally different conditions of lubrication were tested. The first involved chemically clean surfaces from which even the slightest trace of lubricant had been removed. The second provided a very thin film of lubricant duplicating the conditions when the amount of lubricant is inadequate. The third provided an appreciable amount of lubricant so that the bearing surfaces were covered and the oil extended well up on the pivot.

The well lubricated bearings were run for 120 million revolutions without failure or sufficient wear in either the pivot or the jewel to affect the accuracy of the meter appreciably. The dry bearings were in very bad condition at the end of 10 million revolutions; the pivots and jewels were badly worn and

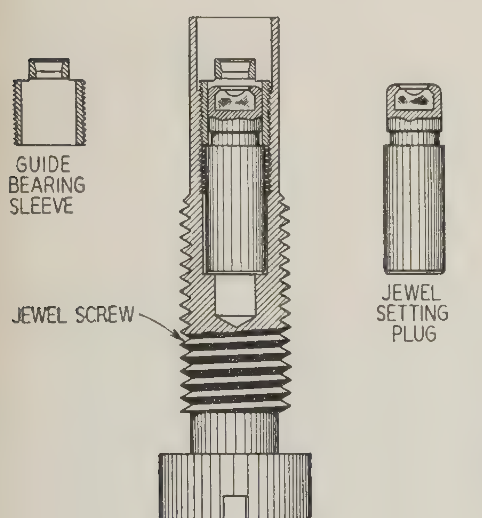


Fig. 1. A jewel screw for pivot bearings of watthour meters, with large oil retaining cup

rust was present in considerable quantities. The film lubricated bearings operated satisfactorily for a short period of time, but apparently the very thin film was not adequate so that wear comparable to that in the dry bearings soon resulted. The fact that the film provided sufficient lubrication for a short time and then failed indicated that the film actually deteriorated because of wear or for other reasons to a point where the lubrication was inadequate.

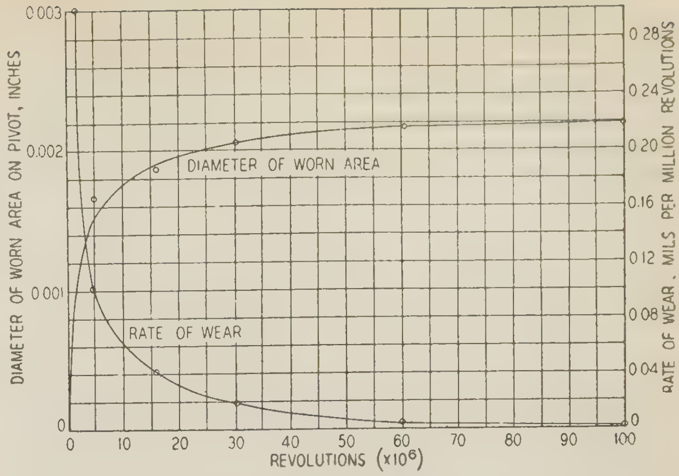


Fig. 2. Average diameter of worn area and rate of wear of 4 well lubricated pivot bearings on accelerated life tests

Confirmation of Accelerated Test Results

While these accelerated tests were being made an extensive examination was made of all the life test data on meters that had been running in the laboratory for several years. The results indicated in the accelerated tests were confirmed. The number of dry bearings or insufficiently lubricated bearings reported from laboratory normal-speed life tests was small, and even in these the accuracy was not affected appreciably; but the dry bearings and the inadequately lubricated bearings were undoubtedly in a worse condition than the well lubricated ones.

Further confirmation was found from the examination of a large number of bearings taken from meters used under actual service conditions. These findings are confirmed also by data in an article recently published by Mr. G. F. Shotter.[5]

An examination of pivots from well oiled bearings that had been operating in meters under normal service conditions for a long time revealed that the worn area on the end of the pivot was usually quite small and apparently independent of the revolutions of the meter. As a result of this observation the worn area on several accelerated life test pivots was measured and plotted against revolutions as shown in figure 2, which is an average for 4 bearings. Evidently the worn area reaches almost its final value after a few million revolutions and from then on increases at a greatly reduced rate. The following computations are interesting in this connection.

The average pressure P over the circular contact area of a sphere of radius R resting on a flat plate and supporting a load W is given by the expression:

$$P = \frac{W}{\pi r^2} \qquad (1)$$

where r is the radius of the circle of contact and was calculated by Dr. Föppl[1] to be

$$r = \left[0.75WR\left(\frac{1-\rho^2}{E}\right)\right]^{1/3} \qquad (2)$$

in which

ρ = Poissens ratio for the pivot steel (0.25)

E = modulus of elasticity for the pivot steel (30×10^6)

5. For all numbered references see list at end of paper.

If W is in pounds and R is in inches, r will be the radius in inches. In the foregoing formulas all the deformation is assumed to take place in the pivot as the steel is much softer than the sapphire.

Combining equations 1 and 2

$$P = \frac{W}{\pi \left[0.75WR\left(\frac{1-\rho^2}{E}\right)\right]^{2/3}} \tag{3}$$

For a standard type of watthour meter:

W = 0.0291 pound
R = 0.0185 inch pivot point radius

Substituting in equation 3 the initial pressure at the bearing point is found to be 172,000 pounds per square inch.

It has been seen that a new pivot bearing is in contact over a very small area initially and that this area is governed by the elastic constants of the material. For a properly designed pivot bearing there is no permanent deformation of the point. Possibly the reason for this is that the center section of the spherical surface in contact tends to be driven up into the main body of the pivot and is resisted by the material adjacent to it which is in tension. The combined stresses are such as to offset one another and result in a working stress well within the strength of the material. After a relatively small number of revolutions the contact area wears to the jewel contour and the pressure decreases until the area is large enough to reduce the bearing pressure to the point where the oil film is able to support the moving system. The variation of pressure with contact area as shown by the curve in figure 3 indicates the rapidity with which the pressure decreases as the area increases. The high pressure accounts for the rapid initial wear and consequently for the rapid rise of the curve shown in figure 2.

An examination of the wear of the jewels of the accelerated life test bearings showed that the jewel wear was smooth and even less than that of the pivots.

Computation of Effect of Bearing Friction on Meter Accuracy

The effect on the accuracy of the meter of the increase in bearing contact area shown in figure 2 may be determined by considering the increased friction torque resulting and its relation to the meter driving torque. For a new pivot and jewel, the contact area being a function of the elastic constants of the materials, the friction torque of the pivot bearing may be expressed by:[2]

$$T_f = \frac{3}{16}\pi\mu W\left[0.75WR\left(\frac{1-\rho^2}{E}\right)\right]^{1/3} \tag{4}$$

where μ represents the coefficient of friction and the other symbols have the same meanings as in the previous formulas.

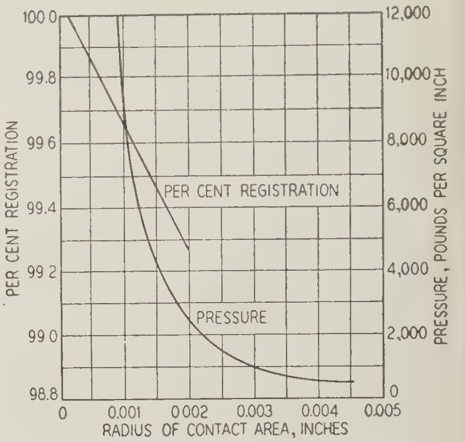
Solving equation 4 for the initial friction torque for the specific meter, T_f = 0.000892 gram-millimeter.

After the pivot has run for 10,000,000 revolutions or more as shown by figure 2, the worn area is large enough to support the load with little or no elastic deformation and the expression for the pivot friction torque changes from equation 4 to:[2]

$$T_f' = {}^2/_3\mu Wr' \tag{5}$$

where r' is measured, or, as in this example, is determined from figure 2 for any desired number of revolutions. Choosing the diameter of worn area from the

Fig. 3. Effect of pivot wear on meter calibration at 5 per cent load, and variation of bearing pressure with wear



curve in figure 2 for 60 million revolutions and solving equation 5, T_f' = 0.00469 gram-millimeter.

The percentage error in registration of a meter at any load resulting from a change in lower bearing friction may be expressed as:

Per cent error =

$$100 \times \frac{\text{Friction torque (final)} - \text{Friction torque (initial)}}{\text{\% Load} \times \text{(Meter driving torque at 100\% load)}} \tag{6}$$

Equation 6 neglects the friction compensating torque as it is very small and has little influence on the result. Substituting the expressions for the torque in equation 6:

Per cent error =

$$100 \times \frac{\frac{2}{3}\mu Wr' - \frac{3}{16}\mu W\left[0.75WR\left(\frac{1-\rho^2}{E}\right)\right]^{1/3}}{\text{\% Load (Meter driving torque at 100\% load)}} \tag{7}$$

The coefficient of friction (μ) in equation 7 is assumed to be the same after the jewel and pivot are worn together as it was initially. In a well oiled bearing the wear is usually smooth and the foregoing assumption is approximately correct.

The curve of meter accuracy as a function of pivot wear shown in figure 3 was plotted from equation 7 for 5 per cent load on a standard meter with the following constants:

W = 0.0291 pound
R = 0.0185 inch
Full load torque = 51.60 gram-millimeters
μ = 0.05
ρ = 0.25
E = 30 × 10[6]

It should be observed from this curve that the change in accuracy is small and comparable with the accuracy of ordinary measurements.

The question naturally arises that if the increase in area on the end of the pivot is desirable, why not

produce this shape at the time the pivot is manufactured? Analysis reveals that the amount of material to be removed is minute and represents a decrease in the pivot length of only 28×10^{-6} inch for a pivot having an initial radius of 0.0185 inch. It is apparent that this cannot be accomplished by any reasonable manufacturing procedure.

In order to obtain the advantages of reduced wear of the bearing by providing a quantity of fluid lubricant, a special design is necessary. The usual type of jewel will hold a small drop of oil but when the pivot is inserted, it causes much of the oil to flow out.

Figure 1 shows a sketch of a new jewel mounting that recently was proposed by the authors. Essentially, the assembly consists of 3 parts: a main screw, a small plug which holds the jewel, and a guide sleeve used to clamp the parts together. When oil is placed in the reservoir of the main screw, it cannot leak out while the screw is in an upright position. If all parts are made carefully to close dimensions, when it becomes necessary to renew the jewel the small plug containing the jewel is the only part to be replaced.

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Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

On this and the following 18 pages appear discussions submitted for publication and approved by the technical committees on papers presented at the sessions on cables, noise, overhead line problems, and electric welding at the 1935 A.I.E.E. winter convention, New York, N. Y., January 22–25. Other discussions of winter convention papers, and authors' closures, will be published in later issues. The first discussions of winter convention papers appear in Electrical Engineering for March 1935, pages 322–35.

Members anywhere are encouraged to submit written discussion of any paper published in Electrical Engineering, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions on papers scheduled for presentation at an A.I.E.E. meeting or convention will be closed 2 weeks after presentation. Discussions should be: (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

Dielectric Properties of Cellulose Paper

Discussion of a paper by J. B. Whitehead and E. W. Greenfield published in the October 1934 issue, pages 1389–96, and in the November 1934 issue, pages 1498–1503, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935. Other discussions of this paper were published in the March 1935 issue, pages 322–4.

R. W. Atkinson (General Cable Corp., Perth Amboy, N. J.): The general effect of moisture on paper insulation is one which is very fully recognized. However, quantitative information concerning the relation between moisture and other properties is sadly lacking. This paper contributes valuable test data on this subject and presents an ingenious method of analysis. I am glad to see the correction which makes it entirely clear that the values of moisture content as calculated and given in the paper are minimum rather than expected values. I am also glad that the authors have supplemented their paper by a calculation of maximum values of moisture content. Comparison of these limits with values actually measured in our laboratory will be of interest. These are presented by A. M. Myers in his discussion.

All of the departure of the paper insulation from the properties of a perfect or zero loss dielectric is attributed by the authors to residual moisture. I am inclined to challenge this assumption. It may be granted that addition of water to the paper increases the departure from the behavior of a perfect dielectric and that extraction of moisture reduces such departure, but that is not evidence that some of the departure is not due to an inherent property of the cellulose or other ingredient of the paper. In other words, it cannot be concluded from the data given that if all of the moisture were removed, the moisture free dielectric would be entirely free of "anomalous" characteristics. Though the conclusions based on this assumption cannot be considered to be proved, they are the less important conclusions of the paper. The facts attributable to moisture added above the driest state obtained are not affected by the assumption. Incidentally, the last traces of water seem to be attached to the paper fibers with a bond as strong as the chemical bond of the material and hence "perfectly dry" fiber is only a hypothetical condition. Any conclusion as to the characteristics of such a material can be drawn only by indirect means and can have no more than an indirect practical significance.

The authors conclude that if due account is taken of changes in electrode dimensions, the dielectric constant of their specimens remains substantially constant over the range of temperature from 25 to 100 degrees

centigrade. We have had occasion to investigate the change in capacitance with temperature on unimpregnated cables with 750,000 circular mil (0.998 inch diameter) conductor and about 400 mils of insulation. It was found that there was a linear increase in capacitance of 4.1 per cent for the temperature range of from 57 to 123 degrees centigrade. The maximum increase in capacitance which can be accounted for by thermal expansion of electrodes (i. e., inner electrode expanded and outer electrode remaining unchanged) is less than $^1/_2$ of 1 per cent, so that an increase of over $3^1/_3$ per cent in capacitance over this range of temperature appears to be an inherent property of the paper-air combination of this cable.

On account of the large dimensions of the cable and because the wall thickness of the dielectric is so large compared with the conductor diameter there is little difficulty in determining within rather narrow limits the possible major physical dimensional changes resulting from temperature change. It appears therefore that the conclusion of the authors that there is substantially no change of capacitance of dry paper with temperature does not apply generally to paper insulation in cables.

Our measurements were made at 60 cycles only. Figures 24 and 25 of the paper indicate, however, that there is practically no difference in the temperature coefficient of capacitance from 60 to 20,000 cycles.

Detailed consideration of the data presented by the authors relating to change of dielectric constant with temperature has developed new matters affecting the analysis presented. These are discussed by Louis Meyerhoff.

Although we have questioned some of the conclusions of the authors, we believe that their data and method of analysis have made a very important contribution toward changing the purely empirical data on the subject to a rational explanation of the behavior of the complex dielectric, paper-water-air, in terms of the basic properties of the components.

A. M. Myers (General Cable Corp., Perth Amboy, N. J.): Several years ago we attempted to measure the rate of drying of wood pulp paper and the change in its dielectric characteristics with per cent of moisture content. Our plan was actually to measure the amount of moisture as removed from the paper. The paper sample was made up of $1^1/_2$ inches wide 5 mil wood pulp paper wound in the form of a flat roll such as is used in ordinary paper taping machines, except that 4 tapes were wound in parallel with two 1 inch lead foil tapes inserted so as to be separated by 2 layers of paper. This sample was placed in a small vacuum oven heated electrically and arranged with automatic temperature control.

Two methods were used for measuring the amount of moisture removed from the paper. For determination of the larger amounts a method of weighing the oven with contained sample was used. This method had a sensitivity of $^1/_4$ gram, the accuracy being of the order of probably $\pm ^1/_2$ gram, or less than 0.1 per cent of the weight of the paper. For determination of amounts of moisture too small to be measured by the difference in weight method, a flow meter was constructed and connected between the kettle and the vacuum pump. This flow meter consisted of a smooth copper tube 18 inches long with a U gauge connected so as to show the drop in pressure between the 2 ends. This drop in pressure is proportional to volumetric rate of flow through the tube. In order to transfer this to gravimetric units a McLeod gauge was arranged adjacent to one end of the tube, and the weight of water was calculated on the basis of the *average* pressure in the flow meter tube. The calibration of the flow meter was checked for both air and water vapor and was found to agree closely with the theoretical values.

The periods of drying at each vacuum step were approximately the same as those used by the authors, but our drying was done at 110 degrees centigrade instead of 100 degrees centigrade, and all measurements were made without releasing the vacuum.

For the purposes of our investigation, we arbitrarily assumed that zero moisture was represented by the driest condition we were able to attain at 110 degrees centigrade. For each step of absolute pressure used in the drying process the corresponding moisture content was taken to be the total moisture removed after the drying at that step had been completed. Since a very small amount of moisture is present even in our final "dry" condition our figures for moisture content should be in every case somewhat lower than the true values.

Since this test gives experimental data concerning the relation between measured moisture content of the paper and its dielectric properties, a comparison of our results with the calculated values should be extremely interesting. After drying at 100 degrees centigrade and 765 millimeters pressure the authors obtained a power factor of 3 per cent, whereas in our tests, even after 90 hours at 110 degrees centigrade and atmospheric pressure the power factor was 20.5 per cent. Similarly, after drying at a pressure of 400 millimeters our power factor was 8 per cent as compared with their 1 per cent. Furthermore (even making allowance for the effect of the different temperatures at which the electrical measurements were made) we were not able to reach a power factor corresponding to the 3 per cent they got at atmospheric pressure until the pressure had been reduced to about 325 millimeters.

Consideration of these large differences between our data and those given in this paper leads us to examine closely if there was anything inherently different in the methods of drying. We notice that, when making measurements, the authors brought the pressure to atmospheric by the admission of dry air to the vacuum oven. This introduces an element of indefiniteness which was also present in some degree in the first readings of our tests, but which we failed to recognize until we came to make this comparison of results. A large number of measurements were made by Whitehead and Greenfield and this repeated admission of dry air followed by reëvacuation approaches what might have been obtained by continuous circulation of dry air. The effectiveness of drying at atmospheric pressure by continuous replacement of the water vapor in the drying chamber by dry air has been pointed out by Whitehead in a previous paper (A.I.E.E. TRANSACTIONS, volume 47, July 1928, page 835). The difference between the power factors obtained at identical pressures under the different conditions of drying may be explained on this basis, since in our tests the vacuum was never broken and the pressure in the drying chamber was largely that of water vapor, while in the authors' experiment the pressure after the introduction of dry air would be largely that of the residual air left in the tank on the subsequent evacuation, the partial pressure of the water vapor being very materially lower than the total pressure. The drying under these conditions will not be at the same rate nor will the final dryness be the same as it would be if the oven were filled with water vapor, since the final degree of drying is more nearly a function of the partial pressure of the water vapor in the oven than of the total pressure as read on the vacuum gauge.

Although, for the above reasons, we cannot expect to find the relations between the moisture content or dielectric properties on the one hand, and the drying pressures on the other to be the same for our conditions as for those of the authors, it is practical to make comparison between the measured amount of water and the calculated minimum values corresponding to different power factors. This comparison is given in table I of this discussion.

Table I—Moisture Content Versus Power Factor

	Per Cent Moisture Content		
Power Factor, Per Cent	Calculated (Minimum) 100° C	Measured 110° C	Estimated From Measurements, 100° C
3	0.26	1.5	1.7
2	0.23	1.4	1.6
1	0.18	0.95	1.2
0.5	0.13	0.45	0.6

The first column shows power factors, the second column the corresponding per cent moisture taken from the curves given in the paper, and the third shows per cent moisture obtained by our measurements. The figures in the fourth column were obtained from our power factor-moisture content curves by calculation on the basis of the temperature coefficient of power factor of dry paper.

It will be seen that the measured quantities of moisture are several times the minimum values determined by calculation, and comparison with the additional data given in Whitehead's presentation indicates that they are of the same order as the calculated maximum values. Our measurements were not so precise as we would have liked, and we have now under way measurements on a commercial length of cable which will give more accurate information.

Louis Meyerhoff (General Cable Corp., Perth Amboy, N. J.): In table V the authors have tabulated the measured expansion of the component parts of their samples as a result of temperature change. From these data it may be calculated readily that the average coefficient of expansion of the inner brass electrode over the range of from 16.2 to 100.3 degrees centigrade is

31×10^{-6} per degree. In the range from 16.2 to 41.8 degrees centigrade the coefficient is 50×10^{-6}, dropping to 18×10^{-6} in the range from 73.5 to 100.3 degrees centigrade.

The average value of 31×10^{-6} found by the authors for the coefficient of expansion of their brass electrode does not agree with values given for brass in standard physical tables, which give for nearly all types of brass a coefficient in the neighborhood of 19×10^{-6} over the range from 0 to 100 degrees centigrade. The drop in coefficient from 50×10^{-6} to 18×10^{-6} as temperature increases is also contrary to what would be expected from generally accepted ideas as to the behavior of metals under going thermal changes. We have given the matter some thought, but have not been able to think of a reasonable explanation. Perhaps the authors can explain this.

Additional analysis clarifies the discussion of dielectric constant with temperature. In figure 20 of the paper it is shown that the geometric capacitance has increased about 5.1 per cent as a result of a temperature increase from 22 to 100 degrees centigrade. In the same range of temperature the insulation thickness of 60 mils has been reduced by about 2.8 mils or 4.7 per cent, the external diameter remaining constant, this decrease in thickness resulting from an increase of the inner electrode diameter of only about 0.22 per cent. By taking into account change in dimensions, the authors find according to figure 25 that the dielectric constant remains substantially the same at all temperatures within the given range. As the specimen is heated from 22 to 100 degrees centigrade, the given mass of paper is compressed in thickness from 60 mils to 57.2 mils, the total volume occupied by the paper being reduced by about 4.6 per cent. In other words, the expansion of the inner electrode, the outer electrode remaining unchanged, not only increases the "electrode system capacitance" as taken into account by the authors, but also increases the specific gravity of the insulation. Data obtained in our laboratory several years ago show that, for an increase in specific gravity of dry paper insulation in the ratio of 1.046 to 1, there is an increase of about $6^1/_2$ per cent in the dielectric constant. The data given in the paper show that the dielectric constant of the specimen has remained substantially constant in spite of this increase in specific gravity. From this it follows that had the insulation retained its original dimensions, the authors' results would have shown a *decrease* of $6^1/_2$ per cent in dielectric constant with *increase* in temperature from 22 to 100 degrees centigrade. This would indicate a *negative* coefficient of capacitance change with temperature as large as the apparent *positive* coefficient.

If the expansion of the inner electrode were only as great as would correspond to the generally accepted coefficient of expansion, it would much more nearly account for the data obtained on capacitance change with temperature.

In calculating moisture content on the basis of observed data the authors use a value of 48 for the dielectric constant of water at 100 degrees centigrade. This agrees with a formula given in the International Critical Tables, volume VI, page 78, which is $\epsilon = 80 - 0.4(t - 20°)$, where ϵ is the dielectric constant of water and t is the temperature in degrees centigrade. According to this formula the dielectric constant is widely different for different temperatures, being, in particular, 80 at 20 degrees centigrade and 48 at 100 degrees centigrade. This furnishes a basis for suggesting that 2 sets of measurements, one at 100 degrees centigrade and one at 20 degrees centigrade, the drying being done at one temperature of course, would produce an additional equation or set of equations with regard to the effect of moisture content on the electrical properties. On the basis of the analysis used by the authors, the value of $C_\infty - C_0$ should be much greater at 20 degrees centigrade than at 100 due to the much higher value of dielectric constant of water. The curves of figures 17 show that there is a greater difference between 60 cycle and geometric capacitance at low than at high temperature, which indicates that it is quite likely that $C_\infty - C_0$ is also greater at low than at high temperature, and this is in line with the above mentioned expectation on the basis of the dielectric constant of water. On the contrary, all effects which we have noted as results of moisture content have been in the direction of increasing effect with increasing temperature. However, our data have been only at 60 cycles and perhaps are not pertinent in this connection. At any rate, systematic measurement at more than one temperature may form the basis of an additional check on the authors' very interesting explanation of the effect of water on the basis of the simple constant of the materials.

If the authors have in contemplation any further work along this line, it will be desirable to give consideration to an arrangement for weighing or otherwise measuring the extracted moisture. By having actual measurements of moisture content, as well as the mathematical maximum and minimum values as determined from electrical measurements at two temperatures, it should be possible to add much to the clearness of the picture as to the probable distribution of moisture in paper.

Herman Halperin (Commonwealth Edison Co., Chicago, Ill.): I found the article by the authors quite interesting, but I was disturbed when I came to the end where the authors state that it appears highly probable "that the increases of capacitance with temperature frequently noted in both cables and laboratory samples are caused by corresponding temperature changes in the dimensions of the electrode systems."

As indicated in the following, this is not corroborated by observations of changes of the capacitance of cable with temperature obtained on 9 samples of 750,000-circular mil, single-conductor 69-kv solid type cables during 54 cycles of accelerated aging tests conducted by the Commonwealth Edison Company.

The increases in capacitance observed on 8 cables during a heating cycle from 25 to 70 degrees centigrade, copper temperature, varied from 0.01 to 0.21 per cent per degree centigrade, i. e., total increases in capacitance as large as $9^1/_2$ per cent. The calculated increase in geometric capacitance of the cables was only about 0.004 per cent per degree centigrade. This latter value was calculated on the assumptions that the diameter of the sheath remained constant after the initial expansion and that only the conductor expanded both radially and longitudinally. The measured changes in capacitance were, therefore, much larger than could be accounted for by geometrical changes.

Since all cables had the same dimensions, it would be expected that temperature changes would cause about the same percentage changes in capacitance for the various cables if geometrical changes were the main cause of the change in capacitance. Actually, the changes in capacitance varied for the cables from 0.01 to 0.21 per cent per degree centigrade.

Instead of the minimum values of capacitance occurring at the minimum temperature, as would be expected from the authors' hypothesis, the minimum values were in all but one case found to occur between 30 and 50 degrees centigrade during heating.

For one cable, the maximum capacitances in 14 heating cycles occurred after cooling down to room temperature, instead of occurring at maximum temperature in line with the authors' ideas; in 7 additional cycles there were 2 maxima in each cycle, one at elevated temperature and one at 30 degrees centigrade while cooling.

There are 3 important differences between the samples discussed by the authors and ordinary cable. First, the diameters of the sheaths of the laboratory samples were practically fixed by binding them with linen thread and by providing longitudinal slots which closed on heating, while cable sheath is cylindrical and is, therefore, subject to the normal thermal expansion of a cylinder. Second, the insulation of the laboratory samples was dry paper, while that of cable contained oil or compound which had a relatively high coefficient of expansion. These differences would lower the theoretical change in capacitance to less than 0.004 per cent per degree centigrade, thus widening the gap between the theoretical and measured changes.

Further, the ratio b/a, that is, ratio of the diameter over the insulation to diameter over the conductor, is about 1.04 for the samples discussed by the authors, while this ratio was about 2.5 for the 66 kv cables on which capacitance measurements were made. From figure 22 of the paper showing capacitance versus the ratio b/a it appears that a value of b/a of 1.04 falls in a portion of the curve where little change in b/a causes a comparatively large change in capacitance, while for a value of 2.5 as for the cables a small change in b/a causes a very small change in capacitance.

Based on these considerations, it appears that the changes in the capacitance of impregnated-paper insulated cable with changes in temperature are due only in small part to thermal changes in the dimensions. Changes in the characteristics of the dielectric itself with temperature are apparently most important.

R. J. Wiseman (Okonite Co., Passaic, N. J.): As a cable manufacturer I always read with great interest papers written by Dr. Whitehead in order to be certain that we have not missed anything in our manufacturing processes. I think the present paper is a very valuable one to cable manufacturers; in fact, it is a sort of a pat on

the back to the latter as it confirms their drying processes. Figures 1, 2, and 3 give curves of change in power factor and capacitance with time and pressure of drying at 100 degrees centigrade. Note that the power factor and capacitance at 1 millimeter pressure are not much different than at 10 millimeters pressure. All manufacturers get about 4 to 5 millimeters pressure when drying cables in large tanks, whereas the authors' samples were dried and tested in a laboratory. These curves show us that it would not be worth while to go to the expense of obtaining 1 millimeter pressure. Also, they help us to assure the cable purchaser that we do thoroughly dry our cables before we impregnate them with oil. When we come to oil filled cables, we can work to much lower pressures—about 50 microns because of the nature of the cable design and the way it is handled, namely, in a lead sheath. Here again we are able to dry our cables thoroughly. I am quite interested in the values of residual moisture as a function of drying pressures as shown in figure 10. The authors computed the moisture content from their test data. I think this is unique. I wish they had also determined it by the well-known physical methods and compared results. According to actual measurements of moisture content of the paper after impregnation and then removal of the oil, we get lower values than are possible according to the curve in figure 10. This may be due to a slightly higher drying temperature that we use. If we assume lower moisture contents than shown in figure 10, then according to figure 11 we should get lower power factors, and we actually do—on dry cables about 0.2 to 0.3 per cent power factor, 0.002 to 0.003 on the scale shown in figure 11.

W. A. Del Mar (Habirshaw Cable and Wire Corp., Yonkers, N. Y.): The formula for the calculation of minimum moisture content is exceedingly interesting and may have applications to other forms of insulation than dry paper. For instance, it might be of great value in the estimation of moisture content of rubber compounds. It would add greatly to the value of the paper if the authors would give either the derivation of the formula or the assumptions upon which the formula is based.

It is obvious that the distribution of moisture in the insulation is unknown. Two extreme conditions may therefore be assumed, one where the moisture is in series with the remainder of the insulation and the other where it is in parallel. Formulas based on these 2 assumptions would seem to give the extremes between which the true moisture content must lie.

A very similar formula to that given in the paper may be derived by considering the moisture to occupy the entire space, but to be attenuated in specific inductive capacity proportionately to its expanded volume. We might refer to this as a ghost condenser. The other condenser would consist of the dry cellulose fibers and might be called a skeleton condenser. If we imagine the ghost and the skeleton to be superimposed, we have the 2 condensers in parallel and their joint capacity is related to the moisture content as in the authors' formula for M except that -1 does not appear after K_w. This would have very little effect on the numerical value of M as K_w is of the order of 48.

I am able to add a few words in substantiation of the discussion by Roper (ELECTRICAL ENGINEERING, March 1935, pages 323–4). Some cable which has been on test on the Commonwealth Edison Company's system for 9 years at about 60 per cent over its rated voltage has been removed and power factor tests made, both of the entire cable and of the individual tapes. It was found that the increase in power factor suffered by the entire cable was many times as great as that suffered by the individual tapes. This can only be interpreted as showing that the deterioration of a cable in service takes place principally in the oil between tapes.

G. M. L. Sommerman (American Steel and Wire Co., Worcester, Mass.): This paper is another in a series of contributions by Doctor Whitehead and his associates in which, by careful control of experimental conditions and accurate measuring technique, they have been able to deduce a number of correlations in the basic properties of a product too often thought to be incapable of rational explanation.

It appears that the relationships between the various electrical properties and moisture, while very striking, can be stated only qualitatively as yet. The amounts of moisture calculated are admittedly probable minimum values. It has been assumed apparently that the moisture is distributed in sheets parallel to the electric field, since this distribution will give the formula for M used. This formula can be put in the form

$$M_p = 100\,\frac{K_0}{K_w - 1}\,\frac{C_\infty - C_0}{C_0} \qquad (1)$$

which, for the values used in the paper, reduces to

$$M_p = 5.0\,\frac{C_\infty - C_0}{C_0} \qquad (2)$$

If the moisture is assumed to be in series distribution, i. e., in thin sheets bounded by equipotential surfaces, a corresponding formula, true for any electrode system, can be derived, thus

$$M_s = 100\,\frac{K_w}{K_w - 1}\cdot\frac{1}{K_\infty}\cdot\frac{C_\infty - C_0}{C_0} \qquad (3)$$

which, for the same values, gives

$$M_s \sim 42\,\frac{C_0}{C_\infty - C_0} \qquad (4)$$

Since the moisture is actually distributed along the walls of capillaries largely perpendicular to the field, the actual effect will be somewhere between those for series and parallel distributions, of the order of

$$M_a \sim 20\,\frac{C_\infty - C_0}{C_0} \qquad (5)$$

It would be interesting to check this figure, since the range of possible variation is rather large, by actual tests for moisture content, such as the standard xylol test. A rough idea of its correctness can be obtained by calculating the moisture content at the beginning of the drying run at 110 degrees centigrade, figure 1 of the paper, at which time $C_\infty = 973$ micromicrofarads. The results are $M_p = 1.2$, $M_s = 10$, and $M_a = 5$ per cent. The last figure is about right since some of the original probable 10 per cent of moisture is removed in heating the specimen up to 110 degrees centigrade.

It also appears that K_w, the dielectric constant of water, may vary considerably with the degree of dryness. Leaving out of consideration chemically combined water, the water present at the condition of greatest dryness is a monomolecular film of adsorbed moisture. These water molecules are probably so tightly bound that they cannot orient appreciably with an applied electric field, so that the dielectric constant is probably little higher than that of electronic polarization only, or about 2. For subsequent adsorbed layers, the forces of attraction are reduced more and more, and the increased freedom of motion gives rise to higher values of dielectric constant, and finally, for the most loosely held water, the full value of 80 is approached asymptotically. Such a variation of the dielectric constant of water with its concentration naturally leads to departures from the linear relation between moisture content and capacity change exemplified in equations 2, 4, and 5. It is interesting to note that the departure is much less for the series distribution (equation 3) than for the parallel distribution (equation 1). The actual behavior can, of course, be checked by the direct tests for moisture content.

Cable System Neutral Grounding Impedance

Discussion of a paper by J. E. Clem published in the January 1935 issue, pages 30–40, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935. Other discussions of this paper were published in the March 1935 issue, page 324.

F. O. Wollaston (Commonwealth Edison Co., Chicago, Ill.): The author's theory applied to the 12 kv system of the Commonwealth Edison Company indicates that with the present 3 ohm neutral resistances, the arcing ground overvoltages would not exceed about 2.3 times normal. This result is not in accord with operating experience. At least 30 per cent of the 12 kv line failures cause overvoltages in excess of 3.2 times normal. This indicates that the proposed criterion for effectively grounded systems is based on the wrong assumptions.

The overvoltages on the 12 kv system were measured by needle gaps connected to some substation busses distributed through the system. The gaps have timing devices which record the time of occurrence of each surge, so that they can be correlated with other occurrences on the system. In the 5 year period ending December 1932, 87 surges were recorded which exceeded 3.2 times normal, and 72 of these were definitely correlated as occurring at the time of line or apparatus failures. The records of line failures show that only about 2 out of the 50 or so 12 kv line failures per year cause a simultaneous or secondary failure in another 12 kv line. These secondary failures invariably occur in cable or joints having insulation of poor quality and so it appears that the surges are relatively harm-

less with the present neutral resistance of 3 ohms. Insulation of fair to excellent quality has never failed from transient voltages on our system.

The data justify the suspicion that there is an element of risk in adopting the proposed criterion, which suspicion is not dispelled by careful reading of the paper. If the resistance per neutral were to be increased from 3 ohms to the theoretical maximum safe value of 21 ohms, calculated from the author's formula, then the overvoltages might become definitely hazardous both to cables and to terminal apparatus. The author states that switching surges would not be increased if our neutral resistance were increased. This statement, if reliable, would dispose of the element of risk if all the surges measured by our spark gaps were switching surges. However, so little is definitely known about system transients that there is no justification for assuming that we are getting nothing but switching surges under fault conditions. We are going to make a more detailed analysis of our data to determine, if possible, the conditions under which the higher transient voltages occur.

In one test on an artificial transmission line (see figure 113, "Electric Transients," Magnusson, Kalin, and Tolmie, first edition) recurrent overvoltages of about $2^1/_4$ times normal occurred through some action of the circuit which was distinctly different from the theory of this paper. The results were equivalent to obtaining $2^1/_2$ times normal voltage on the faulted phase of a 3 phase line with solidly grounded neutral. In cables under fault conditions the electrical circuit has distributed resistance, inductance, and capacitance, and an arc in shunt which represents a highly variable conductance. With the conductance of the arc varying erratically between zero and infinity, an infinite variety of both traveling waves and oscillations may occur, which may reach dangerously high values under some conditions. There is still a good deal of theoretical work and field experimentation to be done before the subject of transients on cable conductors and permissible maximum neutral impedances is satisfactorily settled.

It is news to us to find the author's statement (page 33, column 1) that the operating engineers have tentatively accepted the proposal of the Insulated Power Cable Engineers Association to consider that the limiting safe value of calculated arcing ground overvoltages is 3 times normal. This limit for overvoltages lasting perhaps a few seconds seems unnecessarily conservative in view of our operating experience and the fact that each reel of high voltage cable at the factory withstands a test of about 4 times normal for 15 minutes, and representative samples withstand tests of about 4 times normal for 6 hours.

There are some errors in table V, which deals with the system of the Commonwealth Edison Company. The values in item 1*a* are microfarads, not millifarads. These figures, which are obscurely referred to as values of LK, are values of C_a as defined in the paper. Thus x_a and the resistances in item 4 can be readily calculated from the proposed formula $R = 1.15X_a$, and it will be found that the figures given in item 4 are erroneous. The correct values, reading from left to right, are 34, 21, 537, 654, and 495 ohms. An item of information which should have been given is that the frequency is 25 cycles for the 9 kv system, and 60 cycles for the others. The 9 kv and 12 kv systems are each normally operated in 2 independent parts with only one neutral on each part, the total LK and kilovoltampere shown in items 1*a* and 1*b* being divided between the 2 parts.

R. D. Evans (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The author has presented a formula for giving the relation between system constants to limit the voltage to ground to 3 times normal. The formula is based on the theory of arcing grounds, that is, the phenomenon in which overvoltages are produced by cumulative action of alternate initiation and suppression of an arc to ground. It is evident that the value of the paper depends largely on the prevalence of cumulative arcing grounds. As indicated in the paper, the theory of cumulative arcing grounds is subject to an increasing amount of skepticism. In 1931 Eaton, Peck, and Dunham reported the results of certain tests whose object was to obtain data on cumulative arcing phenomena on aerial lines, but it was found that the voltages with unstable arcs were no higher than with stable arcs.

In supporting his theory Clem cites the early operating experiences with ungrounded neutral systems. While there is no doubt that overvoltages were encountered in the operation of extensive ungrounded neutral systems with aerial lines, we fail to see that it is permissible to draw the conclusion that these voltages were necessarily the result of the mechanism which he has assumed. Overvoltages from grounds and switching operations have been recorded which are comparable in magnitude to the values of cumulative arcing ground voltages calculated according to the theory which assumes that the arc characteristic changes are governed by the fundamental frequency wave. Overvoltages of about this magnitude have been obtained by artificially made grounds in staged tests.

P. A. Jeanne (Bell Telephone Laboratories, Inc., New York, N. Y.): The term c_m in formula 1 of the paper is defined as the average mutual capacitance between pairs of conductors, and later the statement is made that in a 3 phase circuit using shielded cables or single conductor lead sheathed cables c_m becomes infinite. By going back to Clem's previous paper on "Arcing Grounds" (A.I.E.E. TRANSACTIONS, volume 49, July 1930, page 986) it will be found that the mathematical definition of the term C_m shows it as the reciprocal of the coefficient relating the charge on one wire to the potential resulting from it on a second wire in the equations which express potential in terms of charges for a multiconductor system. While under this definition C_m becomes infinite for a shielded cable, it is not mutual capacitance in accordance with the usual understanding of the term. It is true that there has not been unanimity of usage of the term "mutual capacity" but I believe it is more commonly understood to mean the capacitance existing between 2 wires either alone or, if in the presence of other conductors, under certain specified conditions regarding the latter. For instance, the definition of mutual capacitance in the proposed American Standard Definitions reads: "Mutual capacitance between 2 conductors is the capacitance between them when the other $(n - 2)$ conductors, including ground, are connected together and then regarded as an ignored conductor." In this sense the mutual capacitance between pairs in a shielded cable would be equal to half the capacitance from conductor to sheath. Thus, while Clem handles the term c_m properly in the formulas, the definition which he gives to it appears to be in error and is likely to be confusing to those who use his paper.

J. M. Dunham (Bell Telephone Laboratories, Inc., New York, N. Y.): In figure 3, page 34, the author has shown the diagram of the discharge circuit which he used in determining the discharge leakage factor $(1 - a)$. My understanding is that this circuit represents the conditions immediately following arc extinction, and for this condition the capacitance to ground of the previously faulted conductor is a part of the discharge circuit. I should like to ask if the effect of the capacitance to ground of the previously faulted conductor should not be included in the determination of the discharge leakage factor.

At the top of page 35, first column, in the definition of C, it is stated that "C is the capacitance to ground and third conductor, when the third conductor is assumed as grounded, of each of 2 conductors in multiple." Since the third conductor is not grounded during discharge I should like to know why this conductor was assumed grounded.

In equations 77, 78, and 79 on page 39 the last term under the radical should not be squared. This, I believe, is a typographical error. In equation 80 which is obtained by dividing equation 79 by equation 78, not equation 73 by equation 72, as stated, it appears to me that a term $\frac{\sqrt{X_m}}{\sqrt{X_s}}$ has been omitted, since the equation as given can only be obtained if $X_s = X_m$. According to definition, these 2 values are not equivalent. I wonder if this is a typographical error and if not whether table V will be changed when the correct ratio $\frac{R_c}{R_m}$ is used.

J. R. Eaton (Consumers Power Co., Jackson, Mich.): This paper refers primarily to overvoltages which may occur on cable systems; however, a previous paper by the same author applies this theory of overvoltages to overhead transmission systems. The author has referred quite briefly to certain staged tests which were conducted to study overvoltages from arcing grounds. He may refer to tests which were made on the Consumers Power Company system and which possibly warrant further discussion at this time.

The major part of this transmission system, consisting of approximately 2,000 miles of overhead lines ranging in voltage from 11 to 140 kv, is operated with the neutral ungrounded; and since the theory points out that such a system should be frequently

subjected to extreme overvoltages, it is only natural that an extensive study of this phenomenon should be undertaken by the company. The field study of this subject was begun in 1930 and is continuing up to the present time.

In all cases, the tests have consisted of measuring the line to ground voltages at the time of line to ground faults on the transmission system. The measurement of voltage has been made by conventional magnetic oscillographs supplemented in practically all cases by surge voltage recorders installed to record any overvoltage of a frequency too great to be recorded by the magnetic oscillographs. The study has included the measurement of voltage during staged tests and during transient fault conditions occurring on the actual operating system. The staged tests have been conducted on lines varying in length from 1.5 to 226 miles, and at line to line voltages ranging from 57 to 140 kv. Various tests have been made to determine the effect of fault locations with reference to other system apparatus, arcs have been established by almost every conceivable method, and check tests have been made with solid ground faults so that no arcing condition existed.

Details of the staged tests have been reported previously ("Field Studies of Arcing Faults on Power Lines," J. R. Eaton, J. K. Peck, and J. M. Dunham, Electrical Engineering, November 1931, pages 857–60, and "Petersen Coil Tests on 140 Kv System," J. R. North and J. R. Eaton, Electrical Engineering, January 1934, pages 63–74). A description of the records made during transient conditions on the actual operating system of the company is included in the paper by C. L. Gilkeson and P. A. Jeanne ("Overvoltages on Transmission Lines," Electrical Engineering, September 1934, pages 1301–9).

In the 74 individual staged tests and the 350 transients occurring on the operating system, there has not been a single case definitely showing the piling up of voltage with the restriking of the arc as required by either the normal frequency or oscillatory frequency arc extinction theories.

Overvoltages of the order of 3.5 times normal have been recorded on the 140 kv operating system, but are accounted for by an entirely different phenomenon. Moreover, the oscillograms of all these faults showed no behavior peculiar to the arcing ground fault as compared with the solid ground fault. The oscillograms of ground fault currents, that is, the current through the arc made during the staged test, very rarely show any tendency of the arc to extinguish and restrike as is required by the arcing ground theory. In a few cases where restriking was noted, the arc had stretched out to the point that it was unstable and was introducing so much resistance into the circuit that voltage to ground on the sound conductors was lower than during a condition of uninterrupted arc current. Arc current was substantially a power frequency sine wave, having superimposed some third and fifth harmonics.

While it is realized that the existence of any condition cannot be disproved by any amount of negative information, we do feel that, if arcing ground overvoltages occur on overhead lines from a trapping of charge on the line as described in the paper, they evidently require some special condition and very rarely exist on the isolated neutral system of this company. We stand ready to make a thorough study of arcing ground overvoltages whenever somebody can show us a method of producing them on a practical operating system. In writing definite standards, it seems very desirable to give serious consideration to field studies of arcing ground voltages rather than relying entirely on a theoretical analysis.

C. A. Powel (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper again draws attention to the unsatisfactory situation in regard to a definition of what constitutes an effectively grounded system. This was recognized by the subject committee on grounding of which I was chairman in its second report submitted in March 1931. (A.I.E.E. Transactions, volume 50, Sept. 1931, page 892.) The report included certain definitions to make possible a comparison with the first report, but the committee was not satisfied with them and arranged for a companion paper by R. D. Evans and S. H. Wright ("Some Effects of Unbalanced Faults," Electrical Engineering, June 1931, pages 415–20) in which it was shown that a system with the neutral of some transformers or generators connected directly to ground might be less effectively grounded than a neighboring system grounded through resistance or reactance. It was suggested that such terms as "solidly grounded" and "reactance grounded" be dropped and that the "degree of grounding" be expressed as the "ratio of the zero sequence impedance to the positive sequence reactance of the system." It is interesting to note that Clem makes use of this ratio in a term in which he evaluates neutral shift in terms of system constants. It would seem, however, that the zero sequence impedance ratio itself presents a more fundamental relationship than neutral shift.

Transient Voltages on Bonded Cable Sheaths

Discussion of a paper by Herman Halperin, J. E. Clem, and K. W. Miller published in the January 1935 issue, pages 73–82, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935.

E. R. Thomas (The New York Edison Company, New York, N. Y.): In the New York area insulating sheath joints are installed on 100 miles of single conductor cable. The sheath sections are cross-bonded by the Kirke-Searing method. This installation is used on cables operating at 45, 27, and 11 kv. Some of the cable has been in operation since 1928 but to date we have not noticed any effect of a transient voltage of sufficient magnitude to have left any indication of its presence.

This high voltage cable which is operated with cross-bonding connections of the sheath is different in one respect from that discussed by the authors of the paper. The switching operations on the cable are generally confined to other voltages than those at which the cross-bonded cable is operated and, therefore, transformers appear in the electrical circuit as shunt impedances to that part of the circuit which contains the cross-bonded sheaths.

I believe the authors of the paper are to be congratulated in presenting a composite résumé of a subject which is extremely complex in all its phases and I would like to suggest that they might well continue their investigation, particularly to determine what the relative magnitudes of direct current transients may be when cables which have their sheaths cross-bonded are subject to transient voltages incidental with the energizing and discharging of the cables during high voltage tests with rectified current.

Resistance and Reactance of 3-Conductor Cables

Discussion of a paper by E. H. Salter, G. B. Shanklin, and R. J. Wiseman published in the December 1934 issue, pages 1581–9, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935. Other discussions of this paper were published in the March 1935 issue, pages 324–6.

D. W. Roper (Commonwealth Edison Co., Chicago, Ill.): This paper gives for the first time some interesting technical information regarding the reactance of 3 conductor cable with the belted type of insulation and also of shielded conductor cable of 2 different types of construction. The paper calls attention in a gentle way to the precautions which must be observed in ordering cable of different types to be operated in parallel, but the example given by the authors in the first column on page 1585 of the paper is not well chosen. The example would have been more typical if they had discussed the problem of installing a shielded-type 3-conductor cable in parallel with the 350,000 circular-mil 15-kv cable with belted insulation already in service. This is the type of a problem that is ordinarily met by the utility engineers, as by far the larger portion of 3 conductor cable now installed is of the belted type. Reference to figure 5 of the paper shows that no size of shielded conductor cable will operate in parallel with such a line and properly divide the load without an external reactor in series with the belted type of cable already installed. A reference to this figure will also show that the same comments apply to any of the commercial sizes of cable above 4/0 American wire gauge, or 211,600 circular mils.

One of the alleged advantages of the shielded conductor type of 3 conductor 15 kv cable is that it has a larger carrying capacity, because of the better radiating characteristics and the higher permissible operating temperature; but this type of cable also commands a correspondingly higher price. If the additional carrying capacity of the shielded conductor cable is desired, it can be obtained by using a somewhat larger size conductor in 3 conductor belted cable at practically the same cost

per foot, so that in comparing the total cost of the completed installation of 2 lines using these 2 types of cables, the purchaser is faced with the additional cost of the external reactance to be installed in series with the belted cable already in place, in order to make it divide the load properly with the proposed line of shielded conductor cable without any compensating advantages.

W. H. Cole (The Edison Electric Illuminating Co. of Boston, Mass.): Unfortunately the magnitude of the effects of certain well-known fundamentals are not always known or appreciated at the outset when unusual sizes or types of apparatus, equipment, or transmission lines are under consideration or construction. Such a situation appears to have existed some 5 years ago when The Edison Electric Illuminating Company of Boston proposed to install some shielded type transmission cable of unusually large capacity.

As a result the company found itself, early in 1930, in possession of 2 important station tie line cables which did not measure up to their expected value as transmission units within $40,000 of what the company then had a full right to expect, or if the present design value of a-c losses in equivalent conductor size cables are accepted as a basis, the deficiency amounts to approximately $25,000. These deficiencies are of the order of from 5 to 8 per cent. These costs do not include any allowance for station capacity or changes in external reactors required to produce proper division of load between these cables and older cables already in place.

The events leading up to the discovery of the deficiency are substantially as stated by the authors but are not material to this discussion.

The work performed by the joint group of investigators and the authors of this paper should be very useful in future cable practice if properly interpreted. For instance, the data given in figure 5, in my opinion, support the contention that magnetic material has no substantial value in shielded cable construction. I can hardly imagine a case where an engineer would prefer high reactance cable as a means of effecting proper division of load. Cable lines are frequently altered in length or "cut over" and combined with other cables having possibly different destinations. External and more flexible means of controlling load division should, therefore, usually be preferable to the means inherent to intentionally high reactance cable.

The authors find that compact stranding of conductors reduces radial or contact resistance and thus effects a reduction in proximity effect losses. In view of this result, one might expect still lower proximity effect losses with a solid conductor. Granting that solid conductors are not practicable, we should know by actual test the relative magnitude of proximity effect losses in them.

Early in the progress of the work described by the authors I suggested that by test on a full sized cable model proximity effect losses be determined for solid conductors of large cross section. My purpose was to obtain basic information since at that time there seemed reason to doubt the accuracy of published values. I suggest and hope, therefore, that if the authors cannot cause these fundamental determinations to be made, some university or technical institute may undertake the job.

If both isolated strand and solid conductors are prohibitive types of conductors, we should have reliable data for practicable conductor design so that at least we might know toward which construction extreme the trend should be.

Standardization of Noise Meters

R. G. McCurdy, January 1935 issue, pages 14–5.

Noise Measurements for Engineering Purposes

B. G. Churcher, January 1935 issue, pages 55–65.

Measurement of Noise From Power Transformers

A. P. Fugill, December 1934 issue, pages 1603–8.

Measurement of Noise From Small Motors

C. G. Veinott, December 1934 issue, pages 1624–8.

Quieting Substation Equipment

E. J. Abbott, January 1935 issue, pages 20–6.

Discussion of a group of papers presented for oral discussion at the noise session of the winter convention, New York, N. Y., January 23, 1935.

P. L. Alger (General Electric Co., Schenectady, N. Y.): Everybody knows that the public wants quieter living conditions, as manifested by a growing and insistent demand for quieter apparatus. However, very few know how this need is being met, or are conscious that there is any program for making progress in this new field. This symposium demonstrates the progress that has been made in defining and controlling noise and suggests the further progress which we may expect in the future.

At the Institute's convention in Rochester, N. Y., in May 1931, the possibility of the control of noise by design methods was suggested, and our ability to measure it was demonstrated. However, there was no common language for describing noise, and any real understanding of it was confined to a few laboratory experts. Largely stimulated by the discussion there, subsequent discussions led to the formation in January 1932 of the American Standards Association's sectional committee on acoustical measurements and terminology, which brought out in May 1934 the first draft of a proposed standard, establishing an adequate language for describing noise and a fundamental method of determining the loudness of any sound.

Now, we have presented to us the basis of a proposed standard for noise instruments that will enable measurements made by any one anywhere to be truly compared with past and future measurements. When this standard comes into actual use, we shall for the first time have an industrial technique for measuring noise, which may well mark the birth of the real science of noise control.

Papers also have been presented showing how noise instruments may be used to describe and improve noise conditions, forecasting the imminent general use of numerical loudness to describe noise and to specify required noise levels. It is evident that all industries, such as building, air conditioning, domestic appliance, and others concerned with living conditions, will find it of great advantage to take up the use of these new instruments and to so develop their own testing methods that the noise produced by their apparatus may be clearly specified.

Besides this rapid development in the use of noise instruments and noise specifications that may be expected, we may look for the development of accepted levels of quietness for various living conditions. Just as we have comfort levels of temperature, humidity, and light, so may we expect confort levels of quietness for the home, the office, and the street to be determined by the scientists, and established as measures of desirable quality in all forms of apparatus.

E. J. Abbott (nonmember): The general experience at the laboratory of the University of Michigan agrees well with Churcher's observations. We agree with him that no present meter measures loudness as defined, and that if one wishes to determine this quantity it is necessary to use ear comparisons. We also agree that a scale of loudness in which twice as loud numbers correspond to twice as loud sounds is obtained only with a scale approximately like that given in the appendix of his paper. We also agree that ear judgments seem to be a proper basis for such a scale.

Our differences seem to be largely a matter of degree. In making loudness balances we have usually encountered a range of about 20 decibels among the individual observers, while we have never encountered discrepancies of more than 5 decibels between noise meter measurements and the average judgment of a group of observers. We have not encountered the difficulty with harmonic sounds which he reports, although as mentioned in his paper we did make tests on just this type of tone. Measurements show that the loudness of a combination of harmonic notes can be changed by as much as 10 decibels by altering the relative phases of the components, at least at high levels ("The Influence of Phase on Tone Quality and Loudness,"

E. K. Chapin and F. A. Firestone, *Acoustical Society of America Journal*, January 1934, page 173).

From the engineering viewpoint, perhaps the most practical application of sound measurements is to determine the relative importance of various components or sources of noise in order to know what sounds must be reduced in order to obtain quieting and to locate the parts of the mechanism to which attention must be directed. On the basis of these data, experiments are devised after which measurements are made to determine which sounds are changed and how much. Our experience has been that properly weighted and interpreted sound pressure measurements are very satisfactory for this purpose and that such instrumental measurements are far more valuable than audiometric observations for this class of work. As Fugill has pointed out, specifications based on such data appear to be sufficient to insure a given level of quietness, even though the loudness as determined by a jury of observers is not measured.

In connection with Veinott's paper, we have come to place slight confidence in a single sound measurement taken at any position or in any sort of enclosure, even for relative comparisons. For routine inspection of a given type of product, this can sometimes be accomplished after investigation to make sure that proper comparisons are obtained. For use in connection with development, or for comparisons among different models or different types or sizes of unit, conclusions based on single readings are likely to be very misleading.

In the course of the discussion it was pointed out that 2 transformers which are equally loud nearby are not equally loud at a distance if their frequency analyses are different. This is a direct consequence of the variations in frequency response of the ear with level as indicated in figure 2 of my paper. The different types of noise can be differentiated easily by properly weighted instrumental measurements.

Another of the discussers raised the point as to the relative advantages of frequency analyses and total noise readings. We regard these as supplementary rather than alternate measurements and use either or both, depending on the needs of the problem. This symposium was of great interest to me as it appears that we are passing from a consideration of units, instruments, and scales to the application of sound measurements to practical problems, which after all is the essential engineering feature of sound measurement.

L. J. Gorman (The New York Edison Co., New York, N. Y.): The papers of this symposium treat the problem of noise measurement in electrical equipment in a practical manner. There is no doubt of the urgent need for standardization in noise measuring equipment and in the technique for measuring noise in various classes of machinery. It is believed that the symposium will do much to promote the desired standardization.

Our experience during the past 4 years has given us considerable faith in the noise meter as an aid in the practical solution of noise problems as they occur on our system. These problems include noise and vibration from transformers, blowers, and various substation and utilization equipment. Our experience in this work checks very closely with that reported in the papers by Fugill and Abbott. Our procedure for making noise tests is quite similar to that outlined in these papers.

The greatest difficulty in making noise measurements in the field is to obtain locations where the background or street noise is sufficiently low, even during the quiet periods of the early morning, to give satisfactory test conditions. The best that we can expect is about 30 decibels based on the old reference level or 44 decibels based on the tentative reference. When making tests for total noise on transformers in the yard, the surroundings such as building walls, etc., do not seem to have an important influence provided they are distant 50 feet or more from the transformer. Consideration, however, must be given to standing waves and effects of the deflection of sound, particularly in field tests where measurements are made at considerable distances from the source. If the difference between the total noise and the background noise is 10 decibels or more, the background noise will have no material effect on the result. If the difference is less than 10 decibels, a correction must be made.

It is believed that the present noise instrument design can be improved. C. G. Veinott has suggested 2 or 3 desirable modifications from the standpoint of field use. These include a flat frequency response with provision for cutting in a weighting network, and head phones arranged so that the noise can be heard while the reading is taken. The quality index suggested in his paper is often very helpful in measuring total noise where a complete frequency analysis is not warranted. We have found it advantageous to use something quite similar in several of our noise investigations. However, a good analyzer is an essential part of every noise measuring equipment.

The question of a standard of noise and a practical procedure for calibrating and checking noise instruments is of fundamental importance. In so far as we know, there are no authoritative standards by which one manufacturer can make his noise instrument agree with another of different manufacture. There are no practical means by which the purchaser of a noise instrument can be assured that its calibration will agree with one of a different make. As shown by Fugill, instruments of different manufacture may disagree by as much as 8 decibels. Experience has shown that the noise instrument is practical but there is an urgent need for a little standardization in the matter of calibration.

We are now discussing noise measurements in terms of the tentative reference intensity of 10^{-16} watts per square centimeter, corresponding to a pressure reference level of 0.0002 dyne per square centimeter. There are numerous field data on noise based on the reference of 0.001 dyne per square centimeter, and it is believed that there are still in use many noise instruments in which the scale is based on the old reference. When comparisons are made between data based on the old and new reference levels, there is likely to be some confusion unless the difference is kept in mind. The change in reference level has the effect of increasing the noise scale approximately 14 decibels; that is, the scale reading for a given noise based on a reference level of 0.0002 dyne per square centimeter will be 14 decibels higher than the same noise measured with reference to a level of 0.001 dyne per square centimeter.

Our most difficult noise problems have been with comparatively quiet equipment located where the noise is transmitted by vibrations set up in floors and building framework. For this reason, vibration and its measurement and treatment should be very closely correlated with noise studies on electrical and other machinery. It is obvious that machinery noise is the result of some form of mechanical vibration. It seems probable that some relationship can be established and a procedure determined by which noise conditions could be predicted from a knowledge of the vibration. This would be of particular advantage from a manufacturing standpoint, and in locations where noise measurements are not practicable.

H. Fahnoe (nonmember): The papers by Fugill, Abbott, and Churcher cover a large amount of data on the measurement of noise emitted from transformers. They bring out the facts that standardization of noise instruments and auxiliary equipment is very desirable, that under certain specific conditions fairly consistent results can be obtained, and that the results obtained with commercial noise instruments should be carefully analyzed in order to get the proper interpretation.

Fugill, in addition to presenting the experimental data, even at this early stage of the art, suggests that he is ready to include values for permissible noise of transformers in the purchasing specifications for such equipment.

Granted that in the near future it is possible to measure either the total noise of transformers or its components with a fair degree of accuracy under specified conditions, the art has not progressed so far that the designer can predetermine the noise or the distance that a transformer of a new design can be heard. This holds true whether this measure of noise is expressed in decibels, or average vibrational velocity of tank surface, or average amplitude of tank vibration. The manufacturer may therefore be taking some risk if he accepts a hard and fast noise clause in a specification, since it is frequently next to impossible to correct a noisy transformer without a complete redesign.

For the investigation of noise from transformers, the modern noise instrument is a very valuable apparatus for both the manufacturer and the operator. It has enabled the manufacturer to analyze in great detail the source of noise emitted from transformers and thereby suggested remedies for its reduction.

The major fundamental source of transformer noise is the core. In a well built transformer, the tank vibrations caused by the load current are in general only of fundamental frequency (120 cycles in a 60 cycle transformer) and these vibrations are relatively small compared to the vibrations caused by the excitation of the core at the flux densities generally used in power transformers. The core is practically the sole generator of the even and odd harmonic

vibrations present. Depending upon the quality of the steel used in the core, the higher harmonics decrease rapidly with decrease in flux density, leaving the fundamental and second harmonic as the principal vibrations transmitted to the tank surface. Because of the large number of requirements of the tank construction, it is exceedingly difficult to predetermine its vibrational characteristics. A certain amount of experimental data has been obtained which may guide the designer, but the possibility of obtaining partial resonance of a certain wall or cover section is always present.

From the manufacturer's standpoint, the method of specifying transformer noise as decibel "total noise" has many objections from a test standpoint. With the core worked at such a flux density that practically only the first and second harmonics are present, the "total noise" measured with a noise instrument at a relatively large number of locations around the transformer will in general be closely related to the distance at which the transformer can be heard in free space. However, if large extraneous noises are present or interference patterns are produced from surrounding buildings, the "total noise" measurements are of little value. Such measurements should therefore be made in a relatively large open space. Since it would not always be possible to make the test at a definite date, due to unfavorable weather conditions, etc., this method would frequently interfere with the production schedule. Fugill mentions the possibility of making such tests inside the manufacturer's factory buildings at night. In general, the testing department is located close to the generating equipment supplying power to the test. The noise from the rotating machinery will practically completely mask the noise coming from the transformer. We have found that even with the transformer located nearly centrally in a separate large building, such a large number of interference patterns are produced that the "total noise" measured has no relation to the distance the transformer can be heard.

In our investigation we have made great use of measuring the vibrational velocities of the vibrating surfaces by means of a vibration pickup connected to the noise instrument. Where these vibrations have been reduced principally to fundamental and second harmonics, our data seem to indicate that such values when properly weighted will represent some measure of the distance at which the transformer can be heard. These measurements are taken at a large number of regularly spaced points of the tank surface, and where only 2 frequencies are involved, the readings can be taken in a relatively short time. For instance, a 6,000-kva, 3-phase 13,200-volt transformer was analyzed in approximately 4 hours. These measurements of course can be taken in any suitable location except for stray fields. They also might be taken on customers' premises, preferably when it is permissible to disconnect the load. It would have been interesting if Fugill had made such tests on some of the units he investigated, because a considerable amount of experimental data will have to be obtained before definite conclusions can be drawn as to the suitability of such measurements as a measure of the loudness of a transformer.

Measurement of Noise From Power Transformers

Discussion of a paper by A. P. Fugill published in the December 1934 issue, pages 1603–8, and presented for oral discussion at the noise session of the winter convention, New York, N. Y., January 23, 1935.

E. T. Norris (Ferranti Ltd., Hollinwood, England): We have experimented with noise instruments employing frequency weighting networks, but have not found them satisfactory as yet. A number of subjective audiometers, as described in Churcher's paper, are available in this country, and will no doubt find considerable application. The great difficulty, however, is to determine standard conditions of test which will permit direct comparison between transformers working under different operating conditions. In this connection the results of the third group of investigations being carried out by the author will be awaited with interest.

For analysis work and for the most accurate comparison, we have found it necessary to develop an apparatus in which the noise is analyzed by filtering out each component of frequency. In this way the results of every measurement can be expressed in decibels for each component harmonic. Although such an apparatus is much more cumbersome than the subjective audiometer, it is portable, and has the advantage that the effect of extraneous noises is largely eliminated. With this apparatus the distribution of noise emission over the whole surface of transformer cores has been explored and a similar study made on the completed transformer in its tank. The effects of stiffeners and flanges on the natural frequency of tank side vibrations were studied extensively. Sound measurements have also been made on many transformers of different types and sizes on site during normal operating conditions. For this purpose a sound analyzing apparatus was installed in a motor van and sent on tour.

I notice that the author has measured only the noise emitted from the sides of the transformer. This is not usually of prime importance in the case of apparatus installed in the open air. Very often other apparatus or low walls cut off the noise in that direction. Noise is usually most objectionable to local residents, and particularly so at night when the residents are in bed. We found it necessary, therefore, to examine the noise emission from the cover of the transformer, as in many cases this had a more important effect than the sides.

As an alternative to exploring the noise emission over the whole surface of the transformer by means of microphones situated a few inches from the tank walls, we found measurement along a fixed line 25 yards away and 15 feet high a satisfactory method. The horizontal distance of 25 yards is based on the assumed nearest residence and the height of 15 feet represents a bedroom in that residence. For standard comparative measurements the microphone was arranged on a portable tripod of this height.

It appears from our investigations that there is no single and complete solution to the problem. Since much of the noise emission depends upon the natural frequency of vibration of the mechanical parts of the transformer, any change which removes this natural frequency outside the objectionable audible range in either direction will be an improvement. Thus, transformer radiators and plain nonreinforced tank walls (unless circular) do not usually cause much trouble as their natural frequencies are well below 120 cycles. However, increasing the thickness of the tank wall, or adding stiffeners in order to reduce mechanical vibration, may raise the natural frequency and make matters worse by bringing it into the more audible range. Stiffening and clamping, however, become effective if carried far enough to bring the natural frequency above the audible range.

Noise Measurements for Engineering Purposes

Discussion of a paper by B. G. Churcher published in the January 1935 issue, pages 55–65, and presented for oral discussion at the noise session of the winter convention, New York, N. Y., January 23, 1935.

A. P. Fugill (Detroit Edison Co., Detroit, Mich.): Churcher has presented some pertinent conclusions based upon an extensive series of carefully performed experiments. I am particularly interested in the results of his comparisons of noise measurements by the subjective and objective methods, using, respectively, the audiometer with which the noise being measured is balanced against an adjustable standard reference tone until the 2 are judged equal, and the total noise instrument which sums up the sound energy of the component notes in the measured noise, according to a selected weighting curve and converts the results to a readable electrical quantity. In the remainder of this discussion, I shall refer to the former instrument simply as an audiometer and to the latter as a noise instrument.

As I interpret the paper, the experiments showed that while many types of noise gave essentially equal results by both methods of measurement, certain "harmonic" noises which were checked gave values with the audiometer as much as 30 decibels higher than the results obtained with the noise instrument. In view of the thorough manner in which the investigation was carried out, the volume of data obtained, and the lack of conclusive evidence to the contrary, it seems that we should accept Churcher's findings as indicating that such a discrepancy between the 2 methods of measurement actually does exist for certain types of noise. I am particularly concerned with the effect of this conclusion on the use of the noise instrument for the measurement of noise from power transformers. Unfortunately, Churcher did not include this equipment in his experiment, or at least did not mention the fact in his paper. I have a feeling, however, for reasons which will be mentioned shortly, that, for power transformers, this discrepancy dwindles to an insignificant amount.

Let us grant for the moment that this

difference in results is appreciable and see how that affects the use of the noise instrument for specification and acceptance test purposes. If you wish to specify the tolerable noise in a transformer to be purchased, you cannot refer to a table of average values for motor generators, turbines, automobile traffic, and the rustle of leaves, and choose a value which seems to be about what you would like. The best way to determine the

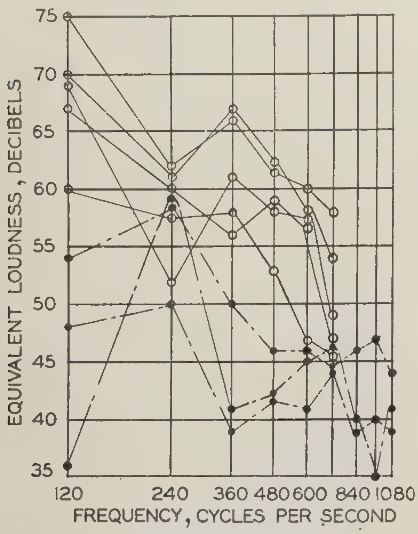


Fig. 1. Analysis of power transformer noise

○ 500-kva single-phase units
● 6,000-kva 3-phase units

value to include in your specifications—I almost am tempted to say the only way at the present time—is to select a transformer installation as similar to the proposed one as possible which, by experience or by a concensus of opinion of competent judges, is deemed acceptable as to noise. Then with a noise instrument as we have done, or with any other method of measurement which by experience has proved itself to be reliable, dependable, and accurate for comparisons of noise from similar equipment, measure the noise from the reference unit to obtain a value to be included in the specifications. When the new unit arrives, measurement of noise from it by the same method will determine whether the specification has been met. Obviously to make such technique valid, the instrument used must give results which are compatible with the impressions obtained by ear, even though the power transformers compared are different in general design. We have used instruments to measure the noise from many different designs of transformers, which by analysis of the component notes we know to have quite different sound patterns, and have always found when any comparison by ear was possible that the transformer noises which gave higher readings on the instrument sounded louder to a person listening to them. Whether 2 noises, one from a power transformer and one from a motor generator or turbine, which gave equal results on the noise instrument, would sound equally loud to a person listening to them is really of no practical importance for this particular purpose although it would make the general situation of noise measurement simpler.

It would be necessary, of course, to specify the type of noise instrument used in setting up the specifications and the manufacturer, if he cared to check the noise, would have to use the same type of instrument, but that will be necessary, regardless of the type of instrument used, until such time as calibration standards are adopted and universally accepted. Looking at the situation from the purely practical viewpoint, the use of the noise instrument for specification and acceptance test purposes assures us that, if the specification is met, we will get a transformer essentially as quiet as we asked for, and that is all that is required of any method for this purpose.

I mentioned at the start that perhaps for power transformers this difference between methods might be negligible. I would like to support this statement by a little data which we have collected. I believe Churcher feels that the audiometer method in which a person listens to a noise with one ear and to a reference tone in an earphone with the other duplicates accurately the impressions received by a person listening to a noise with both ears uncovered in the normal manner. I wonder whether this is always true even with the precautions taken to make it so. Granting that it is, however, his results would indicate that if a person judged a harmonic and a nonharmonic noise to be equal, the noise instrument would give a lower reading for the harmonic noise, and the difference might reach 30 decibels in extreme cases. In addition to the measurements of noise from power transformers, we have used the noise instrument to a limited extent to measure noise from gears, motors, fans, turbines, automobiles, and miscellaneous equipment, and have never found any evidence of this effect. Since most of this equipment was in actual service, there was little opportunity for direct comparisons. quate methods of comparison to judge equality between noises as close as 5 or 10 decibels, we decided to carry out a few experiments under conditions more favorable for direct comparison. Although we are primarily interested in power transformers, we included other harmonic noises more nearly in the class of the ones Churcher investigated, to see if we could detect the effect he found.

As has been stated many times, the court of last resort in all noise problems is the human ear. To be sure, it is at times a fickle and unreliable judge, but we must admit that if complaints of noisy equipment are received at all, they are on the basis of how the equipment sounds and not on the basis of readings on any instrument. Therefore, we thought it best for the few comparisons we had time to make to allow the individual to listen directly to the noise with both ears, unhindered by any mechanical device. The technique of comparison was very simple and one might say unscientific; but we believe it gave us the facts we were seeking. We merely allowed the experimenter to listen naturally with both ears uncovered to 2 noises alternately; one a harmonic noise and the other nonharmonic. The loudness at the ear was modified by changing the distance from the source or by controlling the volume of the source. When the individual decided that both noises sounded equally loud to him, measurement of each noise was made with the noise instrument and the readings compared. If the effect which Churcher found in his tests were pronounced, for the equipment being compared, wide discrepancies should be found in the 2 comparative readings. During the series of experiments, 4 experimenters made a total of about 60 comparisons for a number of different pieces

Table I—Equal Loudness Comparisons Between Harmonic and Nonharmonic Noise, Natural Listening vs. Measurements

Group	Noise Equipment Compared: Harmonic	Noise Equipment Compared: Nonharmonic	Number of Readings	Average Results, Decibels*: Harmonic Noise	Difference: Range	Difference: Average
A . . . 1	500 kva trans.	Automobile engine	10	54	+3 to −3	−0.2
B . . . 1	500 kva trans.	Automobile engine	6	45	+1 to −2	−0.6
C . . . 1	500 kva trans.	Fan on heater	6	48	+2 to −1	−0.5
D . . . 3	100 kva trans.	1/4 hp motor	9	40	+7 to 0	+3.0
E . . . 1	100 kva trans.	1/6 hp motor	4	42	−1 to −3	−2.5
F . . . 1	1.25 kva ind. reg.	Gas lighter	4	39	+6 to −4	+0.6
G . . . 1	1.25 kva ind. reg.	Universal motor No. 1	3	38	+0 to −3	−1.3
H . . . 1 1	0.5 kva trans. 1.25 kva ind. reg.	Universal motor No. 1	3	45	+7 to +3	+3.3
I . . . 1 1	0.5 kva trans. 1.25 kva ind. reg.	Universal motor No. 2	6	44	+6 to 0	+3.5
J . . . 1	Loud speaker	Universal motor No. 2	3	60	+3 to −1	+0.3
K . . . 1	Loud speaker	Universal motor No. 2	4	47	+5 to 0	+1.5

*Results in decibels above the reference pressure o f0.0002 dynes per square centimeter were obtained by average noise instrument measurements for each group after harmonic and nonharmonic noises had been judged equal by ear. The plus sign indicates that the nonharmonic noise gave a higher instrument reading than the harmonic noise.

However, the concensus of opinion of several of our experimenters who have been engaged in this work is that any of these nonharmonic noises which gave a meter reading of from 15 to 30 decibels higher than the noise from a power transformer sounded much louder to the ear. It is not difficult to discern a difference of this amount even after the lapse of a reasonable time. Since it was impossible, of course, under such inadequate methods of comparison to judge equality between noises as close as 5 or 10

of equipment, and the average results for each group of similar comparisons were determined. To produce the harmonic noises, we used a 500-kva single-phase oil-immersed self-cooled transformer, 3 100-kva single-phase O.I.S.C. transformers, a small 0.5 kva filament transformer, a 1.25-kva air-cooled induction regulator, and a magnetic loud speaker excited at 60 cycles. To produce the nonharmonic noises we used 3

automobile engines, a fan on a unit steam radiator used for heating, 2 single-phase fractional horse power induction motors, 2 single-phase fractional horse power commutator type universal motors, and a gas lighter for a domestic furnace.

With this method of comparison, we expected to find that a given individual would be unable to repeat his results consistently on check tests, but we were agreeably surprised to discover that this was not the case. Apparently each person had a definite idea as to the values he considered equally loud, even though the noises being compared were radically different in character so that on check comparisons for the same equipment, but under slightly different conditions, he would repeat within 1 or 2 decibels. As would be expected, there was a greater difference in the results of individuals than of the same person on check tests.

The results of the investigation are given in table I of this discussion. The last column giving the average difference in instrument readings for the 2 classes of noise indicates that only in groups *D*, *H*, and *I* did the effect which Churcher found appear, and then the indication was very slight, 3.5 decibels maximum. In all other cases, and particularly for groups *A*, *B*, and *C* involving the power transformers, when the individual judged the 2 noises to be the same the noise instrument gave equal readings. Obviously, this investigation was not extensive enough to offer as conclusive evidence. Considerably more work would be necessary before the results could be used as definite proof. These facts are offered, however, as an indication that for much of the transformer equipment used by power companies perhaps the noise instrument, after all, does give results compatible with the impressions on the human ear even when compared to nonharmonic noises.

There is one factor I should like to mention which is an additional reason why this might be so. Churcher points out that the fewer the component notes, the less the discrepancy between the 2 methods. Power transformers, and for that matter any distribution transformers we have measured, have 10 or even more measurable components but usually 2 or 3 frequencies predominate. Figure 1 of this discussion shows some analyses of noise from power transformers which are typical for those we have measured. Obviously, the points connected by lines are for one transformer. The magnitude is plotted in terms of equivalent loudness obtained by applying the loudness curves proposed by the American Standards Association, so that each component is shown about as it affects the noise instrument reading. It will be noted that usually 2 or 3 components are about 10 decibels higher than the rest. In all probability, then, power transformer noise compares essentially to the harmonic noises of 2 or 3 components which Churcher measured, and would not show much discrepancy even according to his results.

It is quite clear that much more work, both practical and theoretical, must be done before noise measurement becomes a finished art. The present equipment, however, is an entirely practicable tool and will give satisfactory and correct answers to most noise problems if intelligently used. We personally prefer the noise instrument to any method which depends upon the indefinite character of a pair of human ears, or 2 or 3 pairs, and we believe most power companies will find it more satisfactory. We do not believe that the discoveries Churcher has made invalidate the use of the noise meter for the measurement of the noise of most power equipment, harmonic or nonharmonic. Whether you prefer the audiometer or the noise instrument is of no great importance. The main point is that this equipment is ready for use and unless the power industry and other industries use it in its present form, without waiting until perfection is attained, progress in noise measurement will be unnecessarily retarded.

Control of Transients in Welding Generators

F. B. Hornby, December 1934 issue, pages 1598–1602.

Transient Voltages in Welding Generators

A. R. Miller, September 1934 issue, pages 1296–1301.

Discussion of papers presented for oral discussion at the electric welding session of the winter convention, New York, N. Y., January 23, 1935.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The great divergence of opinion on arc welding and entirely opposite points of view was brought home to me very forcibly during a recent trip to Europe when I made inquiries with regard to such questions as a-c versus d-c welding, bare versus covered electrodes, etc. On the continent there is a strong leaning toward welding with direct current and with bare or lightly covered electrodes for everything except high quality work and very special requirements, while in England there is a preference for a-c welding with covered electrodes for all work. However, in view of the many variables entering into this question, it is not at all surprising to find such differences in opinion.

The material to be welded, the material used in the electrodes and more particularly the materials used for the various types of coatings, the size of the electrodes, the character of the structures to be welded, and the uses made thereof, the amount of current used, the characteristics of the current supply, relation of labor to material costs, the skill of the welder, and a great many other variables make the entire problem one that is very confusing indeed. In addition to this, I feel that much of the difference in opinion can be attributed to the fact that a different type of work is expected in each individual case. In many of the discussions carried on by expert engineers, the quality of the weld is stressed as being of greatest importance, which, of course, is the correct point of view in many cases. However, there is a great deal of work in which quality is not as important a factor as the cost of the weld, which in turn is closely tied up with the speed at which the metal can be deposited. It is quite imaginable that for this latter type of work certain characteristics of the power supply would prove very favorable, while for high quality work different characteristics would be preferable.

Although it is generally conceded that for high quality work covered electrodes are to be preferred, there is still considerable difference in opinion as to whether ordinary work can be done more economically with alternating or direct-current, or with bare or covered electrodes. A rather careful analysis carried on in Germany indicates that with the relatively high cost of covered electrodes and relatively low labor rates for the welding operation, decidedly lower costs can be obtained with bare electrodes. In England, it seems to be the opinion that the lowest costs can be obtained with covered electrodes. Recent indications in this country are that for smaller welds, assuming equal sizes of electrodes and the use of direct current, the cost of welding with covered electrodes compares quite favorably with that done with bare electrodes, while for heavy plate welding the cost with bare electrodes seems to be appreciably lower. However, with the somewhat heavier electrode wire which can be used satisfactorily with covered electrodes, it has been found that in some cases welding of $^1/_4$ inch fillets can be done most economically with covered electrodes; in welding $^1/_2$ inch fillets there seems to be little difference; but for larger fillets the cost with covered electrodes still exceeds that with bare electrodes.

With reference to alternating versus direct current, in using very heavy currents alternating seems to compare favorably with direct both in cost and quality, while with smaller currents direct seems to be in general more advantageous, particularly in cost. From these relations it might be concluded that with heavy direct currents the presence of transients would not be objectionable, while with the smaller direct currents they might be disadvantageous. This in turn may be one reason for the differences in opinion.

On the whole, these considerations indicate that investigations and discussions regarding any one of the variables may be of little value unless the other variables in the cases being compared are similar, or at least such that the difference in them can be definitely evaluated. A few interesting articles have recently appeared covering studies of this nature, but I believe that it would be well for the committee on welding to sponsor further papers covering carefully conducted investigations of this nature.

T. M. Linville (General Electric Co., Schenectady, N. Y.): This discussion is presented to show the transient voltages and currents which occur in the split-pole self-excited generator described by Hornby. The analysis is applicable to any welding generator and is similar to that which Miller has presented, although the method is different in many respects. In addition, the writer wishes to compare Hornby's type of generator with the conventional 4 pole generator having a differentially wound series field from a reactance point of view. Moreover, a foremost object of the discussion is to present 2 criteria for comparing, in the case of 2 or more generators,

the relative stability of the arc and the ease with which it can be ignited.

All welding gnerators consist fundamentally of 2 circuits, the exciting circuit (with constant exciting voltage) and the welding circuit, the latter including the armature and series field of the generator. It is necessary to reduce the magnetic coupling of these 2 circuits in order to produce a good welding machine free from serious transients.

Any discussion of transients ought to be related to their effect upon welding. Hornby concludes his paper by stating that "there is considerable disagreement in regard to the relations between the welding generator characteristics and the production of good welding." However, probably everyone will agree that some surging of current will produce more nearly constant heat at the arc and will result in stronger welds of greater depth. (Ernst Scharz in V.D.I. Zeitschrift, Nov. 15, 1930, volume 74, pages 1565 and 1567, figures 3 and 4, shows photographs of depth of weld showing appreciably deeper welds with a current of 180 amperes when the peaks are 430 amperes than when the peaks are 340 amperes.) However this may be, it is absolutely necessary to limit these surges to the point where the operator may ignite and hold a steady arc without trouble. This latter quality in a welding generator is outstanding. Therefore, analyses such as Miller's applied to actual machines mean a great deal especially when the effect of the transients on the arc stability is known. In this discussion it will be shown how the transients are related to stability.

From these remarks, it is assumed that in designing a welding generator the transients are to be controlled only to the point which will positively insure easy operation for the operator. This does not mean their complete elimination. Such procedure will result in a successful, economical, generator giving the least variation of heat at the weld with a steady, nonsplattering arc, easy to ignite and easy to hold.

Current Transients

Considering the current on sudden changes in arc length or short circuit, the diagrammatic arrangement of windings and connections of the split pole generator have been shown by Hornby in figure 2 of his paper. Let the transient impedance of the field circuit from brush E to brush A be $(r_1 + px_1)$ where p is the operator d/dt, and the total transient impedance of the welding circuit be $(r_2 + px_2)$ exclusive of the arc. Then let x_m be the total mutual inductance between the 2 circuits.

The exciting voltage may be expressed over the working range by

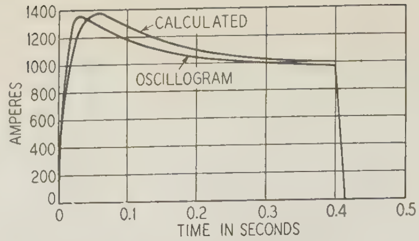
$$e_1 = E + K_2 (i_1 - I_0)$$

where

E = normal open circuit excitation voltage
I_0 = normal open circuit exciting current
i_1 = instantaneous field current
K_2 = volts per ampere of field current
= slope of main pole saturation curve over working range.

Also let

K_3 = slope of main pole saturation curve over working range.
= volts per ampere of armature current.



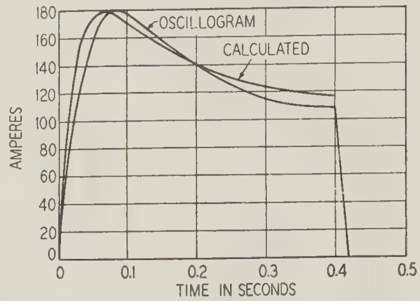


Fig. 1. Comparison of calculated and measured short circuit currents of 400-ampere 40-volt welding generator; 85 volts open circuit

Top: Maximum setting; calculated values from the equation $978 + 837\,\epsilon^{-10.5t} - 1820\,\epsilon^{-56t}$

Bottom: Minimum setting; calculated values from the equation $109 + 164\,\epsilon^{-8.22t} - 273\epsilon^{-56t}$

Finally, the saturation curve of the cross pole is linear where

K_0 = volts per ampere of armature current.
K_1 = volts per ampere of field current.

Then if e_2 is the arc voltage and i_2 the arc current, the voltage equations for the 2 circuits are, for the welding circuit,

$$E + K_2 (i_1 - I_0) + K_1 i_1 + K_3 i_2 - K_0 i_2 = e_2 + (r_2 + px_2)\, i_2 - x_m p i_1 \quad (1)$$

and for the field circuit

$$E + K_2 (i_1 - I_0) + K_3 i_2 = (r_1 + Px_1)\, i_1 - x_m p i_2 \quad (2)$$

Short circuit is equivalent to suddenly applying a voltage equal and opposite to e_2 thereby bringing the arc voltage to zero. Therefore, in place of e_2 is written $(e_2 - e_2\mathbf{1})$ where $\mathbf{1}$ is the operational unit function. The solution of the equations, resulting directly from application of the expansion theorem, gives for the short circuit current

$$i_2 = \frac{(E - K_2 I_0)\,(r_1 + K_1)}{c} + \frac{(r_1 - K_2 + x_1\alpha_1)\, e_2\epsilon^{\alpha_1 t}}{\alpha_1\,(2a\alpha_1 + b)} + \frac{(r_1 - K_2 + x_1\alpha_2)\, e_2\epsilon^{\alpha_2 t}}{\alpha_2\,(2a\alpha_2 + b)} \quad (3)$$

where

$$\begin{aligned} a &= x_1x_2 - x_m^2 \\ b &= (r_1 - K_2)x_2 + (r_2 + K_0 - K_3) \times x_1 - (K_2 + K_1 + K_3)\, x_m \\ c &= (r_2 + K_0 - K_3)\,(r_1 - K_2) - K_3\,(K_2 + K_1) \end{aligned}$$

$$\alpha_1 = \sqrt{\frac{-b + (b^2 - 4ac)}{2a}}$$

$$\alpha_2 = \sqrt{\frac{-b - (b^2 - 4ac)}{2a}}$$

The steady state volt-ampere characteristic is given by the first term of equation 3.

Calculations made for a developmental generator are compared in figure 1 of this discussion with the actual current recorded by the oscillograph.

It should be noted that all of the coefficients in the equations can be determined by simple arithmetic from the design data. That is, the inductance of any circuit is proportional to the product of the turns and the slopes of the saturation curves for the 2 poles. It is not strictly necessary to make elaborate calculations for leakage inductances as these can be taken care of by the ordinary factors used for them in routine design.

For the analysis of current surge on sudden change in arc length it is necessary to find an expression for the arc voltage. Seeliger ("Physick der Gasentladunger," page 286) gives for the voltage of an arc between iron electrodes

$$v = 15.5 + 2.5l + \frac{9.4 + 15l}{i} \quad (4)$$

where l is the length of the arc in millimeters. Ludwig and Silverman ("Arc Stability with D-C Welding Generators," A.I.E.E. Transactions, volume 52, Sept. 1933, pages 987–93) use

$$v = A - Bi$$

for the straight line portion of the characteristic.

The calculation here will be limited to surges along the straight line portion. Therefore, the calculation of current when the arc is drawn out from short circuit is made from equation 1 and 2 substituting $(A\mathbf{1} - e_2)$ for e_2 and $(r_2 - B)$ for r_2. A and B are the coefficients for the Ludwig-Silverman arc characteristic for the length L to which the arc is suddenly drawn.

When the arc is suddenly changed from an initial condition

$$v_0 = A_0 - B_0 i_0$$

the substitutions are

$[(A - A_0)\,\mathbf{1} - e_2 + A_0]$ for e_2

and $(r_2 - B)$ for r_2.

There are 2 impulsive changes, namely, one of e_2 and one of r_2. However, the readjustment of the initial current to the sudden change in r_2 will be neglected. Ordinarily this is satisfactory, for the change in r_2 is small.

Making the above substitution in equations 1 and 2 gives the current for a change in arc length as follows:

$$i_2 = \frac{(-A + E - K_2 I_1)(r_1 - K_2) + (E - K_2 I_0)\,(K_2 + K_1)}{(r_2 - B + K_0 - K_3)\,(r_1 - K_2) - K_3\,(K_2 + K_1)} + \frac{(r_1 - K_2 + x_1\alpha_1)\,(A_0 - A)\epsilon^{\alpha_1 t}}{\alpha_1(2a\alpha_1 + b)} + \frac{(r_1 - K_2 + x_1\alpha_2)\,(A_0 - A)\epsilon^{\alpha_2 t}}{\alpha_2\,(2a\alpha_2 + b)} \quad (5)$$

where

$$\begin{aligned} a &= x_1x_2 - x_m^2 \\ b &= (r_1 - K_2)\, x_m + (r_2 - B + K_0 - K)x_m - (k_2 + K_1 + K_3)x_m \\ c &= (r_2 - B + K_0 - K_3) \times (r_1 - K_2) - K_3\,(K_2 + K_1) \end{aligned}$$

$$\alpha_1 = \sqrt{\frac{-b + (b^2 - 4ac)}{2a}}$$

$$\alpha_2 = \sqrt{\frac{-b - (b^2 - 4ac)}{2a}}$$

This equation is useful in predicting the stability of the arc. For example, if values of A_0, A, and B are substituted (representing an arc suddenly drawn out to 10 millimeters from short circuit) and the

resulting current surges negative it is obvious that the arc will go out. If the current surge is entirely along the straight line portion of the arc characteristic, it is equally certain that the arc can be held. Therefore, it is possible to calculate roughly how far the electrodes may be separated and the arc maintained.

Ludwig and Silverman point out that the arc has a transient characteristic as though it was inductive. That is, the transient characteristic is

$$v = A - Bi + L\frac{di}{dt}$$

The inductive term is neglected in deriving equation 5. Its existence makes it doubly certain that a stable arc according to equation 5 will be stable in reality.

Voltage Recovery

When the arc is extinguished, the voltage recovery is calculated assuming the arc to be broken instantaneously. The formulas apply to any initial arc current or for short circuit.

Immediately upon extinguishing the arc there is an instantaneous induced voltage rising to a relatively large value. This kick voltage will help to hold the arc and possibly will restrike it but the important quality of voltage recovery is not a large kick, but a large sustained voltage available instantaneously to hold the arc. When igniting the arc, the machine is short circuited and the terminal voltage is zero. Then the electrode is pulled away from the work drawing out a 25 to 50 volt arc according to how far the electrode is raised from the work and how skillful the operator is. Ordinarily the energy stored in the reactance of the welding circuit is dissipated very quickly and the arc will continue only if the terminal voltage of the generator has recovered to 25 or 50 volts, as the case may be, in the short interval of time. Since the kick voltage is not important and is not harmfully large, it is not concerned in this calculation. It is desired to calculate the generated terminal voltage. When the arc or short circuit is broken this rises at once to 50 per cent or more of full voltage and then builds up exponentially.

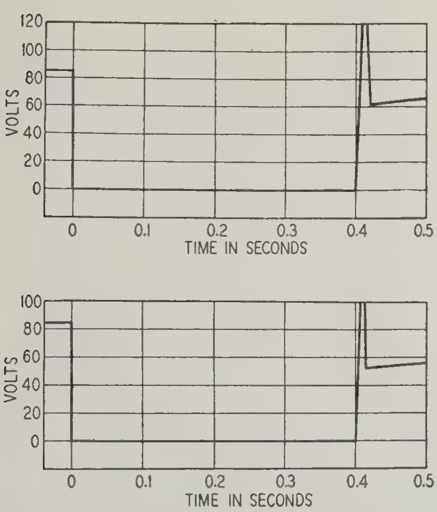


Fig. 2. Curves of voltage recovery after short circuit of the generator of figure 1.

Top: Maximum setting; calculated values from the equation $61 + 24(1 - \epsilon^{-2.5t})$

Bottom: Minimum setting; calculated values from the equation $52 + 33(1 - \epsilon^{-2.4t})$

The calculation is made by determining the field current at the first instant and its decay, expressing the voltage in terms of this current. Induced current arises instantaneously tending to hold the flux linkages of the field circuit constant.

At the first instant, assuming that the current is suddenly interrupted, the field current is

$$i_1 = I_0 - I_2\frac{x_m}{x_1} \qquad (6)$$

where x_m is the mutual inductance between the field circuit and the welding circuit and x_1 is the self-inductance of the field circuit. The interrupted arc current is I_2 and the initial field current I_0.

The instantaneous voltage rise is given in volts by

$$e_2 = \left(I_0 - I_2\frac{x_m}{x_1}\right)(K_1 + K_2) + E - K_2 I_0 \qquad (7)$$

This expression gives practically all of the information desired, the subsequent slow exponential recovery being of no great importance.

The latter can be calculated by determining how the current i_1 behaves. From equations 1 and 2 when the armature circuit is open, there is only

$$E + K_2(i_1 - I_0) = (r_1 + x_1 p)i_1$$

The decrement factor governing the field current is, from this equation

$$\alpha = \frac{r_1 - K_2}{x_1}$$

The sustained current is

$$I_1 = \frac{E - K_2 I_0}{r_1 - K_2}$$

and the initial current is given by eq 6.

Therefore, the complete equation for the field current is

$$i_1 = \frac{E - K_2 I_0}{r_1 - K_2} - \left[\frac{E - K_2 I_0}{r_1 - K_2} - I_0 + I_2\frac{x_m}{x_1}\right]\epsilon\,\frac{-(r_1 - K_2)t}{x_1} \qquad (8)$$

and the complete equation for the voltage recovery is given by

$$e = \frac{(K_1 + K_2)(E - K_2 I_0)}{r_1 - K_2} - \left[\frac{E - K_2 K_1}{r_1 - K_2} - I_0 + I_2\frac{x_m}{x_1}\right] \times (K_1 + K_2)\,\epsilon\,\frac{-(r_1 - K_2)t}{x_1} \qquad (9)$$

For any open circuit voltage e_2,

$$I_0 = \frac{e_2}{K_1 + K_2}$$

When the arc length is suddenly changed, unless the arc is extinguished, the voltage must follow the arc characteristic and about as accurately as can be stated this is

$$e_2 = A - Bi_2$$

where A is the coefficient of the arc characteristic for the length to which the arc is suddenly changed, B is the slope of the same arc characteristic, and i_2 is the arc current given by equation 5.

This voltage expression is not necessary since equation 5 already indicates whether the arc will persist or go out. If it goes out the equation fails and equation 9 applies.

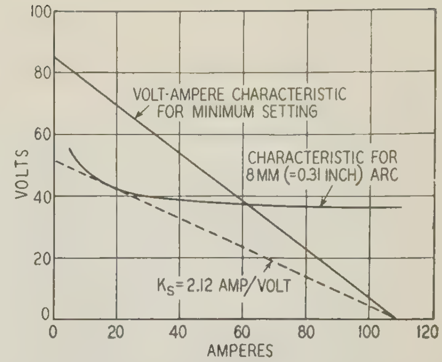


Fig. 3. Ease of ignition and arc stability of split pole welding generator on minimum setting

Arc voltage $= 15.5 + 2.5\,l + \frac{9.4 + 15\,l}{i}$

Ignition factor $= I_{SC}/K_S = 109/2.12 = 51$

Stability factor $= I_W/K_S E_W = 75/2.12 \times 25 = 1.4$

Equation 7 discloses the voltages immediately available to hold the arc and its value is the really important quality of voltage recovery.

Figure 2 shows the calculated and actual voltage recovery when the arc is drawn out and extinguished from short circuit, using a high speed breaker to interrupt the circuit. The machine is the same as in figure 1.

Transient Characteristics and Arc Stability

The foregoing has already indicated how the stability of the welding generator may be foretold from the surge current and voltage recovery calculations. It is possible to estimate the stability of the generator by a very simple calculation or test.

Inspection of equations 3 and 5 shows that the surge of current is always substantially proportional to the sudden change in the terminal or arc voltage. Therefore, the surge current can be expressed by

$$i_s = K_s \Delta e$$

where K_s is the amperes per volt and Δe is the sudden change in the voltage. The value of K_s can be determined most simply by measuring the peak short circuit current with an oscillograph or calculating it from equation 3 and dividing by the sudden change in terminal voltage which, in this case, is the initial voltage.

Having determined K_s it is possible to state what freedom of movement of the electrode is possible without extinguishing the arc. For example, in figure 3 of this discussion the volt-ampere characteristic for the generator of figures 1 and 2 is shown. For this generator, K_s is 16. To determine what maximum length and voltage the arc can have when drawn out from sustained short circuit, the slope, K_s = 16 amperes per volt, is drawn through the short circuit point on the volt-ampere characteristic. Then the arc characteristic, equation 4, is plotted tangent to the line K_s by trial and error. The value of L fitting the tangent characteristic is the maximum separation of the electrodes possible, without "fluttering" the arc. Actually, since the transient characteristic

of the arc is not identical with the static characteristic as given by equation 4, the electrode may be drawn somewhat farther from the work.

Although this method of determining stability may not give values of maximum arc length and voltage which can be accepted prima facie, it serves to show that K_s is a real measure of stability. It is evident from figure 3 that the position of the tangent arc characteristic is fixed not alone by K_s but also by the slope of the volt-ampere characteristic of the generator and by its open circuit voltage.

Therefore, the criterion for easy ignition for any welding generator, at any setting, is the sustained short circuit current divided by K_s. With those generators having the largest value, it will be easiest to strike the arc.

Likewise after the arc is struck and welding is in progress at any average current I_w and voltage E_w, the criterion is $\frac{I_w}{K_s E_w}$. In this, I_w/K_s is a measure of the permissible sudden change in the voltage of the arc. It becomes a definite criterion when it is related to the average arc voltage E_w. Those generators having the largest values will be able to withstand the greater variations of the arc, such as the passage of molten drops and the unsteady hand of the operator.

Comparison of Split Pole and Conventional Generators

Hornby states that the reactance of the split pole generator is greater than that of the conventional generator having a differential series winding. This difference is actually much greater than his remarks show.

The reactance elements and the total reactance have been carefully calculated for 2 generators and are shown for comparison in table I of this discussion. Generator A is a 2 pole generator with split poles and is self-excited. Generator B is an ordinary 4 pole generator having a differential series winding. Both machines have main pole pieces and armature cores which are exactly alike; both give almost identically the same efficiency; both give the same volt-ampere characteristic; and both require the same watts for excitation. Generator B is separately excited from a 125 volt exciter. Generator A is self-excited from a third brush giving a voltage of about 40 volts.

The inductance values are for the minimum setting of the 2 generators giving approximately 50 amperes at 25 volts. At this setting the series turns are all cut in resulting in the maximum magnetic coupling between the welding circuit and the field circuit. This setting creates the worst transients.

It may be noted that the total transient inductance of the welding circuit for the split pole generator A is 10 times as large as for generator B. The magnetic coupling between the welding circuit and the field circuit is very close (0.94) in the ordinary generator and fairly loose (0.64) in the split pole generator. These differences make it possible to operate the split pole generator without a transformer or series reactor.

The very close coupling (0.94) of the ordinary generator results because on the low current setting practically all of the inductance of the generator is from the series field winding which is wound encircling the same flux paths as the field winding encircles. The calculations were made with the 2 windings wound on the poles in the ordinary close proximity to each other. Of course, for higher current settings when some of the series turns are cut out, the coupling becomes looser in both generators.

Table I—Comparison of Generators

	Generator A Split Pole	Generator B Ordinary 4-Pole
Welding amperes (rated)....	400	400
Welding volts (rated)......	40	40
Open circuit volts..........	80	80
Poles.....................	2	4
R.P.M....................	1,785	1,785
Core diameter, inches......	10	10
Core length, inches.........	5	5
Flux per pole, maxwells....	2.6×10^6	1.3×10^6
Excitation watts...........	500	500
Self-inductance (henries) of		
Series field winding......	0.0120	0.0080
Shunt field winding......	1.24	12.5
Armature winding.......	0.0024	0.00054
Commutating pole winding..................	0.0030	0.00089
Mutual inductance (henries) between		
Series and shunt field winding.............	0.084	0.31
Armature and series field winding.............	0.0003	0
Armature and shunt field winding.............	0.0015	0
Armature and comm. pole winding.............	0.0017	0.00043
Total self-inductance of welding circuit (L_w)......	0.0146	0.0086
Total self-inductance of field circuit (L_f).............	1.24	12.5
Total coupling inductance of field and welding circuits (M)....................	0.086	0.31
Coefficient of magnetic coupling between the field and the welding circuit ($M/\sqrt{L_f + L_w}$).........	0.64	0.94
Total transient inductance of welding circuit ($L_w - M^2/L_f$).................	0.0087	0.00087

High Velocity Streams in the Vacuum Arc

Discussion of a paper by E. C. Easton, F. B. Lucas, and F. Creedy published in the November 1934 issue, pages 1454–60, and presented for oral discussion at the electric welding session of the winter convention, New York, N. Y., January 23, 1935.

L. R. Ludwig (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Two very novel results have been presented by the authors, sufficiently so, that care must be used to be certain of their validity. First, the suggestion that the copper arc may exist in 2 conditions, calls for a little more complete explanation of the way the tests were made than has been given in the paper. Each point for copper plotted in the curves of figures 6, 7, and 8 is presumably the result of a single test. It would be of interest to know if there was any lapse of time, change of material, etc., between test points through which A_I and A_{II} were drawn which might explain the difference. Also, were there any measurements of arc drop? It seems that the tentative interpretation of the results, that is, the existence of the arc in 2 conditions, is too broad, even granting the factual evidence of the double curves. All that one could be certain of is that particles are projected with different mean velocities. They might also have different masses, and therefore not imply a different arc condition. Impurities in the copper or oxide could easily account for the result.

The second novel result is the anode stream. Some doubt seems to be cast on the evidence by the deposit of cadmium on the vane from the shielded electrode in a later test. The transient condition of the arc and the short spacing necessitated by striking the arc by contact also introduce uncertainties. The authors are inclined to a thermal theory of the origin of the streams because of the presence of the anode streams as well as that from the cathode. However, they also state that the velocity of the anode stream is independent of the current, and this is certainly surprising on the basis of a thermal theory. Hence, in following the argument, there seems to be a contradiction. In view of these facts, one cannot be certain of the existence of the anode stream from the data presented.

In the curves in figure 11, the fact that 2 curves are obtained suggests either that the attempted relation is meaningless, or that the relation is correct only in part.

Multiple Lightning Strokes

Discussion of a paper by K. B. McEachron published in the December 1934 issue, pages 1633–7, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, pages 332–3.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The author has done a valuable service in presenting this study of lightning phenomena. It is true that while we are able to predict with some assurance the effect of direct hits on transmission lines and even protected apparatus, we know very little about the mechanism of the lightning stroke itself. The work of Schonland, later confirmed by Lloyd and Morris at Pittsfield, is a valuable contribution to our knowledge of the mechanism of lightning. It is interesting to note that a similar phenomenon has been recorded when a discharge takes place between a point and plane as reported by Allebone, Metro-Vickers. As McEachron says and as I have emphasized in the past, it is important that we increase our knowledge of the mechanism of lightning in order to increase our knowledge of the action and effects of lightning. The necessity of thoroughly shielding a transmission line is only now beginning to be appreciated. Some opposition has been experienced in the past when 2 ground wires instead of one have

been recommended to give good shielding.

It would be interesting to know whether multiple strokes occur mostly with severe strokes or with mild strokes. In connection with multiple strokes, I have been accustomed to say that the interval between successive strokes is about $^1/_{100}$ of a second. It is interesting to note that the smallest interval recorded is $^1/_{60}$ second.

Dr. Harold Norinder has made cathode ray oscillograms of lightning surge on transmission lines in which the effect of successive strokes seems to be indicated. Multiple strokes are certainly a factor which must be given consideration in the design of protector tubes.

C. F. Harding (Purdue University, Lafayette, Ind.): Although photographs and a few oscillographs in the past have indicated that some lightning discharges at least are of a multiple type, the data of this paper certainly confirm that fact and show rather surprising evidences of many more multiple paths than had been previously anticipated. Are we sure, however, that all of these records are actual discharges or may not some of the indications be those of reflections from the end of the line, from substation taps, or from the discharge of other protective devices upon the line?

As it is difficult at present to visualize the phenomena of from 30 to 40 discharges in a single so-called lightning stroke or surge, it is hoped that this valuable research may be continued and be accompanied with traveling wave calculations upon the lines thus recorded to determine, if possible, an adequate theory to explain such. Are such discharges the result of the residual charges upon the same cloud similar to those of the familiar Leyden jar experiment, is the cloud recharged in the interval, or are there a sufficient number of leader strokes to account for the many possible parallel paths to ground at relatively wide intervals of time?

It is not surprising that the negative discharges, which are always more numerous than the positive discharges, seek out the positive half cycles of the power supply. Negative surges have been shown by tests upon an experimental 600 kv tower line at Purdue University to attenuate more rapidly because of the neutralization of energy in corona when superimposed upon the positive half cycle. This is analogous to dumping a gas pressure into a vacuum instead of applying it to the back pressure or corona of a negative half cycle. However, is it not possible that such rapid attenuation may produce an oscillatory traveling wave at other points on the line which may account for some of the subsequent oscillographic records?

Furthermore, the methods of measurement described in this paper, which now bridge the previous time gap between 1,000 microseconds and 0.1 to 0.25 second, are of particular interest. The inability of any instrument to record adequately these time intervals has been a distinct deterrent to complete analysis of many phenomena in the past. R. H. George and C. S. Sprague of Purdue University have developed recently an oscillograph upon which the records of a surge of such a period from switching, accidental grounds, or other unstable operation, are magnetically recorded upon a steel tape which is constantly in motion but whose record is automatically and continuously erased until the surge occurs; at which time relays are set in operation to stop the tape after it has traveled about half its length, thus leaving a record of several seconds preceding and following the disturbance. The record is later reproduced from the tape by suitable amplifiers and the ordinary oscillograph.

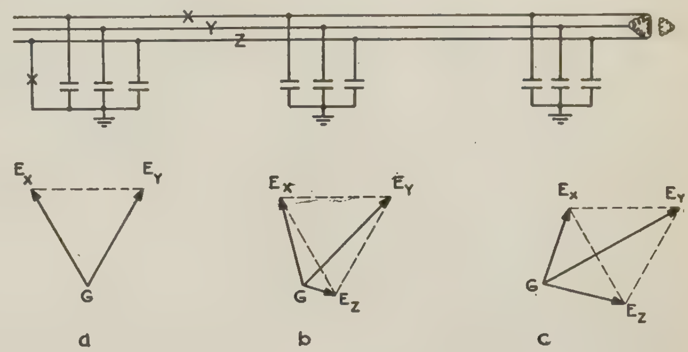
With the general purpose cathode ray oscillograph developed by Professor George and described in his paper "A New Type of Hot Cathode Oscillograph and Its Application to the Automatic Recording of Lightning and Switching Surges," A.I.E.E. TRANSACTIONS, volume 48, July 1929, pages 884–90, such a surge record may be automatically initiated within $^1/_4$ microsecond and a length of film, if the recording drum be used, of over 12 feet may be traced by the electron jet to record the subsequent discharges. This paper should have been listed in the bibliography.

Overvoltages on Transmission Lines

Discussion of a paper by C. L. Gilkeson and P. A. Jeanne published in the September 1934 issue, pages 1301–9, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, page 327.

J. R. Eaton (Consumers Power Co., Jackson, Mich.): In the paper mention is made that the overvoltages on the Consumers Power Company isolated neutral system were of power frequency and could be calculated by the method of symmetrical components. The origin of these overvoltages may be somewhat clarified by reference to figure 1 of this discussion, which is a simplified diagram of a transmission system showing the line to ground capacitance of the conductors at 3 individual points. At *a* it is assumed that the *Z* conductor is faulted, and if the fault is assumed to be solid or voltage across the arc is neglected, the voltage of the *Z* conductor with reference to ground will be zero. The voltages of the *X* and *Y* conductors are as shown in the diagram. At point *b* the voltage of the *Z* conductor will not be zero but will be of some appreciable value due to the flow of fault current through the impedance of the line conductor between *a* and *b*. Therefore, at this point, the voltage of the *Z* conductor will be approximately as shown. Because the fault current is a capacitance current, the E_Z voltage vector will be in such a position that the delta of line to line voltages will not surround the ground point.

Fig. 1. Simplified diagram of transmission system



At a point *c* still farther remote from the point of fault the magnitude of the vector E_Z will be increased to such an extent that it may be larger than the voltage of the unfaulted conductor E_X. As may be seen the voltage E_Y on the *Y* conductor is now several times the normal line to ground voltage. This voltage condition was recorded by many oscillograms during ground fault conditions.

A Carrier Current Relay Installation

Discussion of a paper by O. A. Browne and W. L. Vest, Jr., published in the January 1935 issue, pages 109–15, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, pages 333–4.

H. P. Sleeper (Public Service Electric and Gas Co., Newark, N. J.): Like all new developments this one must be put through a period of trial and test. All operating engineers will be interested in the reasons stated for the changing of the relay system from a standard balanced and time element single line relay scheme to a high speed scheme. The authors state definitely that it was done to minimize damage to lines with resulting interruptions, principally caused by lightning flashovers. Of course, general service conditions would also be improved by the lessened system disturbances from reduced voltage dips as a result of the shortened time of clearing faults. It is also interesting to note that changing the relay scheme was decided to be the cheapest possible method of effecting these results. It is a progressive company indeed which will recognize today the wisdom of spending money solely for an improvement in quality of service to its customers.

It is probable that this particular installation did not offer a typical case where the costs of all available forms of relaying can be

compared directly, but was undoubtedly influenced by the presence of multiended lines, that is, lines with more than 2 terminals each. This, of course, would cause both balanced and distance relay schemes to suffer a disadvantage and cause the sequential clearing of many faults with a resultant increase in fault clearing times. Obviously, the only scheme which would cause the simultaneous clearing of all faults would be a differential scheme, of which pilot wire or its equivalent offers the only solution. The choice of pilot wire relaying, of which carrier current relaying is a branch, was automatically determined by the design of the transmission system.

The relay engineer is interested in the reasons for choosing carrier current pilot wire protection as compared with metallic pilot wire protection. It is unfortunate that the paper did not give further data on the economics of these 2 schemes, particularly since the communication companies have recently expressed their desire to acquire such business by offering attractive rates. Systems in other parts of the country, particularly the south, have found the economics to favor the metallic pilot wire scheme using cables leased from communication companies. It is hoped that the authors will present further data on this phase of the subject.

It is noted that the authors quote 8 cycles as the time setting on phase and ground relays at all terminals. This of course means a total clearing time of approximately 16 cycles (8 cycles breaker time) for any fault on the transmission system. This is a great improvement over the 50 to 60 cycles minimum time quoted for distance relays on the same system, and presumably even higher times with the superseded balanced and single line relaying. It may, therefore, seem trite for the writer to state that the time of 8 cycles for the relays seems long. It must, however, be recalled that modern high speed relays are now available to operate in a time of 1 to 3 cycles and therefore their average operating time is a quarter of that of the relays quoted. The effective reduction in fault clearing time would be, therefore, from 16 cycles to 10 cycles, or a reduction of about 38 per cent. While such time savings are small in magnitude, experience indicates that fault damage progresses as some power of time and can therefore be capitalized.

Scanning the operating results obtained, it will be noted that 87 per cent correct relay operation was obtained in the period indicated. It is appreciated that this covered the period of initial operation and therefore no doubt included many difficulties such as one experiences with any original installation. However, and with no thought of being critical but merely analytical, it would seem that this percentage is low when it is compared with the present day operating results of standard relay schemes, which on most large systems have the percentage of correct relay operations annually in the upper nineties. It would be interesting to relay engineers if the authors were to give further information as to the basic source of the failures and incorrect operations in order that those of us without close contact could more readily analyze the inherent failure probability of carrier current relaying as compared with other commercial relaying schemes.

From a general operating standpoint, it is noted that 51 per cent of all faults were double line faults. This seems very high to the writer and it would be interesting if the authors were to state the causes if data are available, and particularly whether the causes are believed to be mostly initial double faults or single faults communicated to the second line. This latter point is especially pertinent to relay engineers who will agree that modern relaying, with associated high speed circuit interruption, plus, of course, proper tower design, should eliminate almost completely communicated faults on double circuit towers.

Commenting on the relay scheme described, I believe there is an unnecessary operating hazard introduced in the 8 hour interim between the manual operating checks described in the paragraph on "Maintenance." All circuits of other types of standard protective relays are today capable of continuous supervision by proper control circuit design, at practically no additional expense. It would seem that this feature should be capable of incorporation in carrier current relay protection. Another undesirable feature of the equipment described is the necessity of using dynamotors to provide closely regulated alternating potential for the carrier equipment. It would seem that carrier current equipment could be designed so as to be capable of using potential with a commercial variation of ± 5 per cent.

Lastly, it is the writer's opinion that a relay scheme which requires all relays on the system to operate correctly for each fault is fundamentally wrong. The probability of failure is obviously increased directly with the number of relays installed and the percentage of correct operations is bound to be adversely affected, as compared with the scheme where only the relays on the affected section are involved. If such equipment is not commercially available it would seem that the desirability of research work by operating companies and especially manufacturers is indicated.

Lightning Performance of 220 Kv Lines

Discussion of a paper prepared by the lightning and insulator subcommittee of the A.I.E.E. committee on power transmission and distribution published in the November 1934 issue, pages 1443–7, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Except for the Wallenpaupack line no performance records of 220 kv lines have been published. These records have been available to those interested in their performance, but should be published. Of the lines cited in this report, only the following were designed after the theoretical studies of direct stroke were made available:

1. New England Power Co., Comerford-Tewkesbury line.
2. Pennsylvania Water and Power Co., Safe Harbor line.
3. Philadelphia Electric Co., 29.6 miles of Plymouth Meeting-Rosedale line.
4. City of Los Angeles line.

Other lower voltage lines which have been built more or less according to new ideas are:

1. Osage River line between St. Louis and Bagnall operating at 138 kv.
2. Cincinnati-Louisville line, 132 kv.
3. Circuit around Indianapolis, 132 kv.

All these lines have shown good lightning records during the short time they have been in service. In each of these, great care was taken to obtain good shielding.

The practice of insetting the ground wire is for economic reasons and the fear of dancing conductors. A small inset apparently does not appreciably reduce the shielding effect of 2 ground wires.

Regarding the matter of tower footing grounds, too much emphasis cannot be laid on the fact that with 220 kv insulation, 14 to 16 insulators, it is imperative to obtain 10 ohms or less if lightning proof operation is to be expected. The alternative is the use of counterpoises. The effect of counterpoises is not yet theoretically well understood, but more ample confirmation of their effectiveness seems to be at hand. I for one am glad that such ample confirmation that the requirement of 12 ohms or less for tower footing resistance is not too low has been presented of late ("Lightning Investigation on a 220 Kv System," Edgar Bell, Electrical Engineering, August 1934, pages 1188–94, and "Lightning Investigation on Transmission Lines—IV," W. W. Lewis and C. A. Foust, same issue, pages 1180–6). So many engineers have thought in the past that these values were unreasonable and simply plucked out of the air. As an actual fact, quite early in the development of direct stroke theory they appeared as reasonable values for 220 kv lines approaching lightning proof characteristics. No doubt the addition of counterpoises would have a beneficial effect on lines where the tower footing resistances are high, such as the New England line. I wish to emphasize 2 points:

1. Low footing resistance with poor shielding will not give good performance.
2. Good shielding without low tower footing will not give good performance.

A balanced design requires good shielding and tower footing resistance below 10 ohms.

J. T. Lusignan, Jr. (Ohio Brass Co., Mansfield, Ohio): In table II of the paper the new Boulder Dam line of the City of Los Angeles is listed as number 18. While there is no service record to report as yet on this line, perhaps a discussion of the lightning protection and insulation arrangement chosen by the designing engineers would be of interest.

As noted in the table, each circuit is equipped with 2 ground wires. These are arranged, except with greater clearances, as on the Safe Harbor line of the Pennsylvania Water and Power Co., which has had a remarkable lightning record. The counterpoise system on the Boulder Dam line, however, is somewhat more elaborate than any used heretofore. As noted at the bottom of page 1445 it is a combination of both the radial and continuous or parallel types and in effect incorporates the advantages claimed for both of these types.

With the above network for receiving and carrying the currents of all lightning strokes directed toward the conductors, the engineers have calculated the approximate voltage wave which may appear across the insulator strings. In each case, obviously,

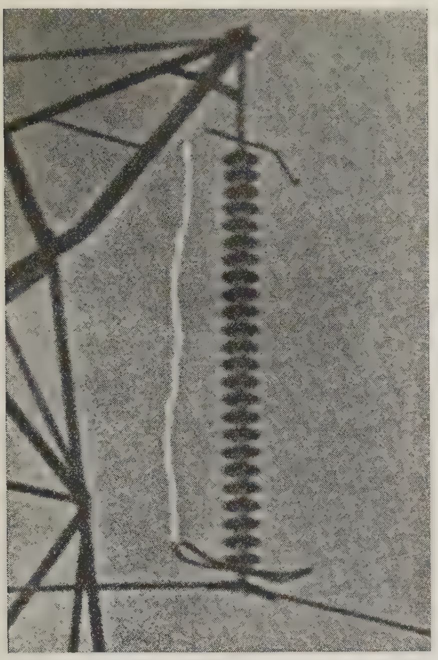


Fig. 1. Flashover between shields of insulator string

this will be the difference between the voltage wave of the tower top and the net wave induced on the conductor by the ground wire and counterpoise waves. Assuming a negative stroke of approximately 15,000 kv to be practically the most severe to be encountered, they have determined that the voltage wave from the conductor to the tower, and the one to be sustained by the insulators, rises abruptly to slightly less than 3,000 kv, remains flat for about 2 or 3 microseconds, and then drops rapidly to zero. Accordingly, in all laboratory flashover studies and measurements on line insulation a wave simulating the above was used.

The suspension string chosen, as noted in table II, consists of 24 insulator units of 10 inch diameter and 5 inch spacing. The grading shields finally selected, however, were not the ring arrangement indicated in the table, since at the time the table data were collected rings had only tentatively been chosen. As a result of laboratory studies conducted later a new form of shielding arrangement was developed which proved appreciably simpler, cheaper, and lighter than the rings originally considered. Briefly, the line shield is in the form of a figure 8 with the center line of the 2 loops parallel to and directly above the conductor. The ground electrode is merely a pair of strap horns with ends turned up to prevent corona and to possess as much mass as possible to resist arc fusion.

The above shielding arrangement was designed to perform the following principle functions: protect the conductor and insulator units from arc damage; and eliminate corona on the insulator units. The line and ground electrodes were so shaped and dimensioned that all flashovers occurred between their outer edges and free of the insulator units. The above calculated lightning wave conditions were simulated in these tests by removing all series resistance from the 3,000 kv impulse generator and

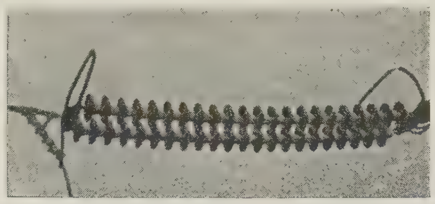


Fig. 2. Flashover test on shields of dead end insulator string

securing a practically flat top wave which reached crest in $^1/_2$ microsecond and caused flashover in approximately 3 microseconds. Figure 1 of this discussion illustrates a typical flashover secured under the above conditions. Since the relaying and switching arrangement of the line is designed so as to interrupt all flashovers within 6 cycles, it is apparent that there is little chance of the arc moving from its initial path between shielding electrodes and free of the insulators and conductor.

A simplified shielding arrangement was developed in the same manner for the dead end insulator strings. Figure 2 illustrates a typical flashover test on the final arrangement chosen. Shielding loops were used only on the upper sides of the strings since it was possible to establish flashovers between them under all circumstances. At the line end of the string the conductor jumper beneath it was found sufficient to provide the proper electrostatic field control on that side for reducing corona, thereby eliminating the need for a double shielding loop there.

Constant-Current D-C Transmission

Discussion of a paper by C. H. Willis, B. D. Bedford, and F. R. Elder published in the January 1935 issue, pages 102–8, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, pages 327–9.

Herman Halperin (Commonwealth Edison Co., Chicago, Ill.): In considering the use of d-c transmission on a metropolitan system such as that of the Commonwealth Edison Company, one of the first questions is the proper ratio of the direct to alternating voltage for a given thickness of insulation in underground cable. Based on short time breakdown tests at room temperature on either thin laboratory samples of impregnated paper insulation or on short samples of cable, the literature shows that various investigators have found ratios ranging from about 2 to 5. The Association of Edison Illuminating Companies cable specifications give a ratio of 2.4. There are no data for the proper ratios for operating conditions at various temperatures over periods of many years and it would be necessary to obtain such data before d-c transmission can be used on underground cable in a commercial manner on a large scale. Of course, the higher the ratio, the larger would be the increase in carrying capacity of an underground cable by the use of d-c transmission instead of 3 phase a-c transmission.

Assuming a d-c/a-c ratio of 3.0 for our 3-conductor 12-kv cables, the operating voltage may be increased from 12 kv, 3 phase, to about 40 kv for direct current. From what information we have available, it appears that this voltage can probably be satisfactorily withstood in the joints. However, if we assume the same ratio for 66 kv cable, it will probably be necessary to make the joints about 18 inches longer than they now are. This would require lengthening the manholes in many cases, if existing 66 kv lines were used for d-c transmission. Here again it appears that data on the proper d-c/a-c ratio over periods of years are necessary.

Assuming a 4 mile line of 500,000 circular mil 3-conductor 12-kv cable, and a d-c/a-c ratio of 3, then the carrying capacity of this cable in the winter would be increased from about 9,000 kva to about 20,000 kva by going to d-c transmission. The corresponding investment saving in lines would be, roughly, $70,000. This means that for d-c transmission to be economically attractive, the extra installed cost for the use of the conversion apparatus at the 2 ends of the line should be less than $70,000.

There are usually either 2 or 4 of our 66 kv lines between station terminals with the result that the 6 or 12 single conductor 750,000 circular mil cables could be split up into 3 or 6 new d-c transmission lines. Again, assuming a d-c/a-c ratio of 3, the carrying capacity for each cable could be increased in the winter from about 20,000 kva to about 65,000 kva by going to d-c transmission. Using our present costs for our new size of 2,100,000 circular mil 66 kv cables which have a carrying capacity of about 115,000 kva per line in the winter, the investment saving by going to d-c transmission on the existing 750,000 circular mil cables on a typical 6 mile line would be approximately $450,000 for the 2 cables that would be used in the d-c transmission for a converted line. The d-c terminal apparatus would have to be adequate for 230 kv between terminals and about 570 amperes for the d-c side, or about 130,000 kva. With the use of direct current on these lines it would be necessary for such apparatus not only to be satisfactory, but the extra installed cost of the new terminal apparatus including space for it to be less than about $375,000 for each new d-c line, allowing for the cost of rebuilding joints, lengthening manholes, and making changes at the ends of each line.

My impression from a study of the apparatus and from what general information I have received leads to the conclusion that considerably more progress will have to be made before the d-c transmission is economically attractive for converting existing Chicago lines or for the use of such transmission for new lines.

The d-c system does have better possibilities where the lines are longer and it ap-

pears to me that possibly, in time, sufficient progress will be made in reducing the cost that where there may now be a question, for example, as to whether overhead transmission should be used, it will be answered because of the economic gain of d-c transmission on long underground lines.

L. W. Chubb (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper is very interesting and shows some valuable oscillograms under operating conditions. Over 20 years ago, when it was thought that the electrolytic capacitor could be produced and operated at a low cost per kilovoltampere. I worked on various systems of d-c transmission, constant current transmission, and multiple power and lighting over the same supply lines. At that time, d-c transmission and constant current transmission seemed rather attractive. They required some type of an inverter; a great deal of work was done and the mercury vapor inverter was developed. At that time it was called a "vacuum type inverted converter" (U.S. patent number 1,347,894).

The monocyclic bridge was used in the constant current transmission system to convert from constant potential to constant current and *vice versa*. This was a single phase monocyclic square using electrolytic capacitors in the capacitance arms, instead of a 3 phase network as shown in the paper. I considered that d-c transmission at constant current would be of importance in transmitting power for great distances. However, the more practical engineers, who knew more about the problems of power transmission and distribution, soon pointed out some of the great disadvantages and we lost our enthusiasm for the various combinations.

Calculations showed no great advantage in line economies. For a direct and constant current, I suggested the use of a single transmission line and ground return. Ground return could, of course, be used, as there would be no telephone interference especially if sufficient inductance were inserted in the line. Then the disadvantages of line insulation were pointed out. A string of high voltage insulators on direct current service has the voltage divided, so that the sections of highest resistance must stand most of the voltage. Any equalization scheme results in some leakage current. Leakage at many points will, of course, be a great disadvantage in a constant current system. Another great disadvantage in the constant current d-c system is that the circuits cannot easily be arranged so that power can be taken off at intermediate points.

After reviewing the features of the constant current and constant potential systems and doing a great deal of experimental work on inverters, electrolytic capacitors, and constant current systems, we came to the conclusion that constant potential alternating current seemed the most practical system, in view of the above disadvantages and the fact that the high power electrolytic capacitor did not give as expected low power factor at reasonable cost per kilovoltampere. The inverter at that time was also new and the development far from complete. With the tools of today, a system such as described by the authors may have some specific applications, such as cable crossings. Here again it seems as though the constant potential d-c system will be the more economical, and safer because overloads with the constant current system result in high voltage on the cable.

On page 107 the authors state that the monocyclic networks cause no undesirable transient conditions. I can remember that this was not true in the case of the constant current systems using single phase monocyclic networks. Under overload conditions the voltage of the constant current side of the network will go up to a high value. On short circuit there must be some such protection as allowing the line to short circuit through a spark gap, or overload breakers in the constant potential line (U.S. patent number 1,270,785).

When the high-voltage constant-current circuit is thus short circuited, on overloads, the condensers in the arms of the monocyclic network are charged to a high voltage and this high impulse voltage is suddenly impressed upon the constant potential circuit. During our experimental work, this serious impulse transient was so severe that it caused sparkovers or breakdown in the constant potential circuit.

The severe voltage kick suggested a similar circuit for making an impulse generator giving definite amplitude. It seems that the 3 phase system will be subject to the same difficulty and give serious punishment to the constant potential circuit and tubes.

It would seem as though in spite of the further development of high voltage rectifiers and inverters, the great disadvantages of the high voltage constant current system are still with us and it is felt that it will not prove economical, except in specific applications, because of the high cost of the static capacitor and inductor kilovoltamperes required.

R. D. Evans (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In the introductory part of the paper there is some speculation as to the possibilities of d-c transmission. In this connection it may be of interest to review briefly the results of a study made some time ago on d-c versus a-c transmission by aerial lines. An economic comparison was made for transmission over distances from 100 to 400 miles using (1) the conventional a-c system and (2) high voltage d-c transmission with a-c generation and a-c utilization. The comparison was made on the basis of a 2-circuit a-c system and a 3-circuit d-c system, which made it possible for the transmission line to be identical, thus avoiding the possibility of error in figuring the cost of the principal item, the line itself. The a-c system was designed for 230-kv 3-phase 60-cycle operation; the d-c system was designed for operation at 376 kv between lines. Thus the d-c system voltage to ground was taken as equal to the crest of the a-c system voltage to ground, though many engineers question whether so favorable a ratio will actually be obtained. The comparison was based on the transmission of large blocks of power using the most economical loading per circuit and a relatively large conductor.

In view of the fact that rectifiers and inverters of high capacity and voltage are not available commercially, it was decided to express the results of the study in the terms of the maximum permissible cost of the rectifiers and inverters at each end which would make the d-c system competitive with the a-c system. The results are given in the accompanying table.

Transmission Distance, Miles	Maximum Permissible Cost of Conversion Equipment at Each End, Dollars per Kilowatt
100	2.70
200	8.70
300	15.20
400	22.20

These figures were based on the cost of transmission line with capitalized values for losses at $140 per maximum kilowatt plus $160 per average kilowatt assuming a 60 per cent load factor. Transmission costs for the a-c system were based on the line with sectionalizing circuit breakers and intermediate and receiver condensers as required. The transmission costs for the d-c system were based on the line and the conversion apparatus at each end including receiver condensers. The losses chargeable to conversion were estimated at 1 per cent at each end, which incidentally is the figure mentioned by the authors. The conversion losses include not only those in the conversion apparatus itself but also the losses in filters, voltage dividers, exciting transformers, and accessories, and additional losses in the associated transformers.

It is to be noted that the maximum permissible cost for conversion equipment must include not only the first cost of the apparatus but also installation and capitalized figures for maintenance and replacement, since they have no corresponding elements in the a-c system.

With the constant current system described by the authors, it is obvious that the cost elements of the constant potential system are involved and the monocyclic equipment in addition.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): For the transmission of large blocks of power over long distances by overhead lines, I think that constant potential d-c transmission will prove to be more economical than constant current transmission. Such lines when laid out with due regard to protection against lightning will rarely suffer short circuits, and, therefore, the advantages of the constant current system in limiting fault currents do not appear to be of much importance.

The authors have stressed the inherent reversibility of power flow in the scheme described in the paper. There are, however, some requirements as to kilovoltampere capacity which limit the value of this feature. In a monocyclic square the kilovoltampere capacities in the reactors and capacitors depend upon the network used and the direction of power flow. The networks assumed in the paper include (1) the network of figure 4 for the inverter and (2) the same network for the rectifier but with reactors and capacitors interchanged. The authors point out that the networks for

the rectifier and inverter are not the same and that the preferred network takes less kilovoltampere capacity in inductors and reactors. For unity power factor it is stated that the total kilovoltampere in inductors and in capacitors each amounts to 57 per cent of the transmitted load, these kilovoltampere capacities being required at each end. The authors do not, however, point out that if the direction of power flow is reversed the total kilovoltampere capacity in reactors and capacitors is increased from 57 per cent to 173 per cent at each end. Consequently, the apparatus has a much lower rating for power flowing in the reverse direction than for power flowing in the normal direction. This constitutes a serious limitation in the scheme from the standpoint of inherent action as to reversibility of power flow. With lagging power factor load the kilovoltampere capacities of reactors and capacitors are altered, some being increased, others being decreased. However, the ratio of maximum capacity for the reversed direction of power flow may become many times the kilovoltampere capacity for the normal direction.

It is, of course, possible to perform switching operations and to use the more efficient type of network for each direction of power flow. However, such a system loses some of the apparent advantages of inherent reversibility. These considerations indicate that control of grid potentials will in the future probably be relied upon to provide for reversibility.

R. E. Hellmund and C. F. Wagner (both of Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The possibility of d-c high-voltage transmission has been an interesting speculation for a great many years; however, practical applications have not been forthcoming for the following reasons:

1. Commercial apparatus for the purpose has not been available. (This applied not only to the conversion apparatus but also to other factors, such as relay protecting schemes, lightning arresting devices, line insulators proved to be suitable for a given continuous voltage, etc.)
2. Extensive investigations of the system from an economic point of view indicate that at present d-c transmission has little chance of competing successfully with a-c systems, except perhaps in the transmission of large blocks of power over long distances and possibly in some exceptional cases where transmission by cable is necessary.

This paper points out correctly that some of the problems that have confronted engineers in constant voltage systems present lesser difficulties in the case of a constant current system. The principal advantage of the latter is its relative stability under various load and fault conditions either in the line or in the converting equipment, and from this point of view it appears to be very attractive indeed.

It is pointed out in the paper that the occurrence of a short circuit will result in no damage to any equipment on the line even though it should persist for a considerable period. It must not be overlooked, however, that even though a short circuit in the line does not cause any damage, it nevertheless means a service interruption; as a matter of fact, for all practical purposes no more power can be transmitted during a complete short circuit than is possible with the line completely disconnected. Again, there is the question of how an arc on the line, which may have been caused either by lightning or perhaps by a temporary short circuit resulting from birds or branches contacting the line, will act under varying line conditions. Although the short circuit can be easily interrupted by a switch, as described in the paper, there may be instances, especially with the higher voltages, where the arc is likely to persist and clearing of the line may be necessary to interrupt it. On the whole, it is likely that the problem of short time fault currents, especially those involving an arc, can be handled about as well in a constant voltage system. It seems relatively easy to clear such faults by having the converter grids block conduction for a few cycles, which would have the effect of a circuit breaker opening and reclosing in an extremely short time.

Another advantage of the constant current d-c system mentioned in the paper is that a change from conversion to inversion in the converting apparatus takes place automatically. This is interesting, but in the majority of transmissions where power usually is transmitted from a mouth of mine steam plant or a hydroelectric plant, such a change is not often found to be a practical requirement.

It is indicated further that a constant current system is advantageous in overcoming certain difficulties encountered in connection with hot cathode devices. This is a very desirable characteristic, but the same difficulties might be overcome also by other types of converting apparatus which are more suitable for operation as inverters because of the shorter deionizing time.

It is stated in the paper that the losses in the conversion devices of the constant current d-c system can be held relatively low, i. e., in the order of 2 per cent of the power transmitted. At full load this is not any different from what would be found in the constant voltage system. However, in the constant current system the losses in the line, which constitute the greater part of the total loss, remain constant with changes in load and this in turn means that the all day efficiency may become rather low unless the load factor of the line is very good. In this respect the system is at a disadvantage in comparison with the constant voltage system.

It appears from the foregoing that the advantages of the constant current system in comparison with those of the constant voltage system may not necessarily be of great practical importance. It therefore seems that the very appreciable increase in cost caused by the addition of the apparatus needed for the monocyclic square, together with the reduced average efficiency, is too high a price to pay for the advantages claimed. Consequently, from an economic point of view, the chances of the d-c system in competition with the a-c system are not enhanced by the use of the constant current feature.

At present it seems that the economic limitations will not permit many practical applications of the d-c system in the near future. One of the reasons for this is that in actual practice applications are very rare where appreciable amounts of power have to be transmitted over great distances and where, therefore, direct current compares reasonably well with alternating current. In the majority of cases having several points of power supply and many points of power delivery, the cost of the necessary conversion apparatus is rather unfavorable for the use of d-c transmission systems. Studies have been made of the possibility of combining transmission with frequency changing, such as might be done when power from a 60 cycle system is delivered at some distance to a single phase railway system. Here the conversion apparatus for the d-c transmission would at the same time take the place of the frequency changing apparatus, which might lead to a rather economical system. However, it was found that even in such cases there is usually a need for 60 cycle ties at the far end of the line in addition to the 25 cycle load, thus causing additional complications.

It is not intended to detract in any way from the merits of a study as covered in the paper as it is only through such efforts that progress can be made in furthering any arrangement departing appreciably from existing standards. Moreover, economic relations are changing continually and schemes that are not competitive today may be in the future. There is also a wide variation in conditions to be met and it would not be surprising if d-c transmission of some kind or other would work out both advantageously and economically in such cases, for instance, as in the transmission of power from Scandinavia to Germany by means of cables across the Baltic Sea. In an instance like this the investment for the cable may prove to be such an important factor that the extra cost for the conversion apparatus at the terminals will be of secondary importance. Other economical applications of d-c lines may be found in connection with weak tie lines between large a-c systems.

The possibility of using conversion apparatus other than that of the hot cathode type has been suggested in the previous remarks. Mention might be made of the rectifier developed by Professor Marx in Germany. In this device the arc, instead of being operated in vacuum, vapors, or low pressure gases, is operated in air with air currents flowing between the electrodes. The air currents move the arc continuously on the electrodes, thus minimizing the burning and also serving to extinguish the arc at the end of each cycle. Superimposed high voltages are used to reëstablish the arc when desired. Professor Marx feels that his device is especially suitable for high voltage d-c transmission. However, since his device has a relatively high arc drop and consequent high losses, it does not appear to be very suitable for a constant current system. In view of the fact that such high losses would remain constant for varying loads, the all day efficiency would be very unfavorably influenced by the high arc drop.

In considering the suitability of various types of devices for conversion, great importance must be attached to the economic application of such devices for various current and voltage ranges. It would, therefore, be of interest to have a statement from the authors as to what they consider the limiting values of the tubes under present conditions and, more particularly, whether they believe that cascading of the tubes will be necessary for voltages needed in power transmission.

News

Of Institute and Related Activities

The Summer Convention at Cornell University

Attractive plans which will be of interest to a large number of the Institute's membership are in progress for the 51st annual summer convention to be held on the campus of Cornell University at Ithaca, N. Y., June 24–28, 1935. The campus, situated on a hill at an elevation of about 500 feet above Cayuga Lake, and the surrounding country are well known for their scenic beauty and they provide an ideal setting for the convention. An enlarged program consisting of 10 technical sessions and a number of informal conferences or round table meetings, some of which will be of special interest to Students and the younger members, will be held. The evenings will be devoted mainly to social functions.

Aside from the usual business features and the professional sessions good facilities for golf and tennis will be available. Also, other features, including an outing to Taughhannock State Park with a shore dinner, and a trip to the Corning Glass Works, are being planned. Taughhannock Falls is the highest falls east of the "Rockies."

A.S.M.E. to Meet the Preceding Week

The semi-annual meeting of The American Society of Mechanical Engineers will be held in Cincinnati, Ohio, June 19–21, 1935. These dates are Wednesday, Thursday, and Friday, of the week immediately preceding the Institute's summer convention at Ithaca. Inasmuch as there are many engineers who hold membership in both organizations, the A.S.M.E. has purposely departed from its usual practice of scheduling meetings to begin on Monday, in order to accommodate those who may wish to attend both meetings. Technical papers on a variety of subjects will be presented at the A.S.M.E. meeting, and a side trip to Norris Dam is scheduled by the A.S.M.E. for June 22. Members making this inspection trip should be able to arrive at Ithaca, in time for the beginning of the A.I.E.E. meeting.

A.I.E.E. Program

The papers for the 10 technical sessions are being published in Electrical Engineering. In addition to the 4 papers published in the February issue which deal with protective devices, 2 timely papers on this subject have been added to the program. One of these treats the new high speed impulse oil circuit breaker for the Boulder Dam–Los Angeles transmission line, and the other which is a companion paper adds valuable information for the determination of circuit recovery rates. These 2 papers, in conjunction with 2 other papers in the session on power transmission, which give the general features and the engineering features of the Boulder Dam–Los Angeles transmission system, should prove of unusual interest.

For those theoretically inclined and interested in electrical machinery and measurements several very good papers appeared in the March issue. Two of the machinery papers have to do with saturated synchronous reactance and commutation, while the measurements paper treats the precise speed control of d-c machines. Another paper also in the March issue explained the objectives and practical value of the advanced course in engineering given by the General Electric Company. This paper should prove of interest to many educators. Several other papers on the program appear in this issue and the publication of these and other papers considerably in advance of the convention will permit time for the careful preparation of good discussion.

As many as 13 informal conferences or round table meetings now are being planned on various subjects. Some of these will be of particular interest to students and members of faculties, as they will consider such matters as research in engineering schools, engineering education, the future of the electrical industry and opportunities for students. Others will have to do with electrical machinery, noise, and research on insulating oils.

More complete information on various features of the convention will appear in subsequent issues. Arrange your plans now so as to be able to attend the annual summer convention during the week of June 24 at Ithaca, N. Y., the home of Cornell University. The dormitories and the Cornell cafeteria will be open, as well as the hotels, and they will provide good facilities at moderate prices.

General Committee Appointed

President J. Allen Johnson has appointed the members of the general committee in charge of arrangements for the 1935 summer convention. These members are as follows:

R. F Chamberlain, *chairman*
W. H. Timbie, *vice chairman*
A. C. Stevens, *secretary-treasurer*

P. L. Alger	M. G. Malti
W. C. Ballard	True McLean
C. H. Bissell	W. E. Meserve
L. A. Burckmyer	B. K Northrop
R. N. Conwell	A. C. Stallman
E. P. Harder	I. Melville Stein
V. Karapetoff	E. M. Strong
P. M. Lincoln	J. O. West
J. T. Littleton	J. P. Wood

W. M. Young

Membership—

Mr. Institute Member:

The bogey of the membership committee is to do better each month than in the corresponding month of the previous year. For February the results were as follows:

	February 1935	February 1934
New member applications received (from other than enrolled Students)	61	43
New member applications received from enrolled Students	349	275
Members reinstated	51	27

In new member applications we have passed the thousand mark, 1095 applications having been received as of March 1, 1935, with 2 more months to go this fiscal year. And better still, new member applications have been received from every one of the 61 Institute Sections.

Chairman National Membership Committee

Pacific Coast Convention Committee Appointed

The general committee in charge of arrangements for the Institute's 1935 Pacific Coast convention to be held at Seattle, Wash., August 27–30, 1935, has been appointed by Pres. J. Allen Johnson, and the members are already busy with arrangements which will insure a successful convention.

In the following list are given the chairman, vice chairman, secretary, and the members of the committee; of these, 7 are chairmen of subcommittees, as indicated.

E. A. Loew, *chairman*
L. B. Robinson, *vice chairman*
G. H. Walker, *secretary*

F. J. Bartholomew	F. O. McMillan
A. M. Bohnert	H. T. Plumb
Walter Brenton	C. E. Rogers
Fred Garrison	R. W. Sorenson
R. H. Hull	J. A. Thaler

G. L. Hoard, meetings and papers
E. B. Hansen, hotel and registrations
L. B. Robinson, finance
R. U. Muffley, entertainment
Wellington Rupp, transportation
G. E. Quinan, golf
J. H. Kelly, publicity

Engineering Society Officers to Hold Joint Meeting

Officers and directors of the national societies of civil, mining and metallurgical, mechanical, and electrical engineers, and of their several jointly sponsored functional organizations will all meet together for dinner Monday, May 20, 1935, at the Engineers' Club in New York, N. Y., according to plans recently announced by United Engineering Trustees, Inc., acting for the societies in sponsoring the proposed meeting. This is the first time in the history of the engineering societies that any such meeting has been undertaken and it is considered to be an important and significant step toward the establishment of a broader and clearer understanding of the scope and significance of the work carried on jointly by the several participating societies.

A wide variety of technical and other activities of importance to every branch of the engineering profession is now, and for many years has been, carried on by the agencies jointly created and sponsored by the engineering societies: United Engineering Trustees, Inc., and its 2 departments, The Engineering Societies Library and The Engineering Foundation; American Standards Association; the Division of Engineering and Industrial Research of the National Research Council; Engineering Societies' Employment Service, and Engineers' National Relief Fund; American Engineering Council; and, more recently, Engineers' Council for Professional Development. The activities, ideals, and procedures of each of these agencies will be described and explained concisely by society representatives long associated with the work in each case.

With a better understanding thus established among the personnel of the governing bodies of the several societies, it is hoped that more direct channels will be established through which the individual members of the societies may become better acquainted with the variety of professional services actually directly available to them. This, in turn, is important from at least 2 angles: first, in order that each member may know how to make use of these services, and second, that each member may realize the extent to which his own small contribution is magnified through effective coöperation.

Plans for this joint dinner meeting have grown out of discussions between the United Engineering Trustees and the secretaries of the founder societies that began in January. The committee in charge of the affair includes Dr. Alfred D. Flinn, director of The Engineering Foundation, *chairman;* H. V. Coes, president of United Engineering Trustees, Inc., *honorary chairman;* George T. Seabury, secretary, American Society of Civil Engineers; A. B. Parsons, secretary, American Institute of Mining and Metallurgical Engineers; C. E. Davies, secretary, American Society of Mechanical Engineers; H. H. Henline, Secretary, American Institute of Electrical Engineers; and John Arms, secretary, United Engineering Trustees, Inc.

Headquarters for the 1935 Summer Convention

MAIN entrance to Willard Straight Hall on the campus of Cornell University, Ithaca, N. Y. This building will be used as the headquarters for the A.I.E.E. 1935 summer convention, to be held in Ithaca, June 24–28. During the college year, this building serves as a social center for students and faculty. It contains dining rooms, large and small rooms for reading, conversation, and games, hotel facilities, theater, soda bar, and barber shop.

Great Lakes District to Meet at Purdue

Announcement has been made that the meeting of the Great Lakes District of the A.I.E.E. scheduled for October 24–25, 1935, will be held on the campus of Purdue University at West Lafayette, Ind. A student convention will be held in conjunction with the District meeting. The principal meetings will be in the electrical engineering building.

The general committee in charge of arrangements for this meeting is as follows:

G. G. Post, vice president, Great Lakes District (number 5)
A. G. Dewares, secretary, Great Lakes District (number 5)

F. R. Finehout	T. F. Irvine
D. H. Hanson	O. Kiltie
C. F. Harding	E. B. Kurtz

C. V. Mueller

South West District Meeting Fully Arranged

All is in readiness for the South West District meeting of the Institute to be held on April 24–26, 1935, at Oklahoma City, Okla., with headquarters at the Skirvin Hotel.

The committee has arranged a program of 5 technical sessions covering a variety of interesting subjects. There will be a session on distribution and transmission, involving the economics and application of regulating and circuit interrupting devices. A session is being arranged on coördination of insulation and surge protection of lines and equipment, including a paper on field testing of insulation. Papers will be presented on new metering practices, involving economic and engineering trends. There will be a symposium on the subject of engineering education. Other interesting topics that will be presented are relays, communication, cable sheath corrosion, regulators, and vacuum tubes. In connection with the presentation of the paper on vacuum tubes there will be a demonstration of d-c power transmission.

It is the intention to allow as much time as possible for the discussion of the technical papers. All who are in position to contribute to the discussion are urged to come prepared to do so.

On Thursday evening the convention banquet (informal) will be held, followed by dancing and bridge. Four inspection trips and a golf tournament are scheduled on Thursday afternoon. Special entertainment will be provided for the visiting women.

The complete program, with other information relative to the inspection, recreation, and social events was given in ELEC-

TRICAL ENGINEERING for March 1935, page 336–8. Complete your plans now to attend this meeting. A registration card is being mailed to all members in the South West District and nearby Sections, which should be filled in and returned promptly.

E.C.P.D. Embarks Upon Student Guidance Program

In furtherance of its charter objective "to enhance the professional status of the engineer through educational activities, "the Engineers' Council for Professional Development is now placing in operation another important part of its program. Recognizing that the first essential in improving the status of the engineering profession is improvement in the quality of men entering the profession, E.C.P.D. through its committee on student selection and guidance has entered upon a program designed to provide opportunity for boys in secondary schools who may be interested in engineering to make direct contact with individual members of the several participating professional societies who can give them sympathetic advice in the matter of the choice of their career.

The Engineers' Council for Professional Development is an agency created and jointly sponsored by the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, the American Institute of Electrical Engineers, the Society for the Promotion of Engineering Education, the American Institute of Chemical Engineers, and the National Council of State Boards of Engineering Examiners. It was organized October 3, 1932, and functions through 4 standing committees: student selection and guidance, engineering schools, professional training, and professional recognition. The intended field of service of each of these committees corresponds to 1 of the 4 major periods in the development of an engineer: first, the selection of a career; then the acquisition of technical training of recognized merit; then, after graduation, the period of first practical experience as a junior engineer; and finally the certification as a full-fledged and qualified engineer.

The personnel of the committee on student selection and guidance is as follows: R. L. Sackett, dean, college of engineering, Pennsylvania State College, State College, *chairman;* O. J. Ferguson (A'05, F'13), dean, college of engineering, University of Nebraska, Lincoln; W. B. Plank, professor of mining engineering, Lafayette College, Easton, Pa.; H. N. Davis, president, Stevens Institute of Technology, Hoboken, N. J.; T. Keith Legaré, secretary, N.C.S.B.E.E., Columbia, S. C.; R. H. Jacobs, Englewood, N. J.; and V. M. Palmer, industrial economy engineer, Eastman Kodak Company, Rochester, N. Y.

Through the instrumentality of this committee, officers of the local units of the participating societies throughout the United States have been called upon to form in each locality "a sympathetic, understanding committee, which will actively promote guidance through contact and advice with the students, high school principals, vocational counselors, and others." Engineering schools throughout the country also are being asked to cooperate. The detailed program of each local committee of course will depend upon local conditions, but all will be guided by the common objective; a better understanding of the educational requirements of and vocational opportunities for engineers "in order that only those may seek entrance to the profession who have the high quality, aptitude, and capacity which are required of its members."

To meet the need for information written in terms and forms understandable and appealing to the immature and inexperienced student, to his high school teacher, and to his parents, the E.C.P.D. committee on student selection and guidance has, after a wide canvass, selected the booklet "Engineering, a Career—a Culture" as the most satisfactory pamphlet for guidance use. This attractive 64 page pamphlet was prepared by the educational research committee of The Engineering Foundation late in 1932, and already over 50,000 copies have been distributed to engineers, teachers, and others interested in the subject. This pamphlet is descriptive of the profession of engineering—of its spheres of action, of the training and the qualities required for successful pursuit; of the obligations which it imposes, and the rewards which it affords. Also, the practical usefulness of an engineering education in vocations other than engineering is illustrated by the experiences of many men in divers callings. Copies of this pamphlet are still available and may be obtained from The Secretary, Engineers' Council for Professional Development, 29 West 39th Street, New York, N. Y. (prices: 15 cents per copy, 10 cents in lots of 50).

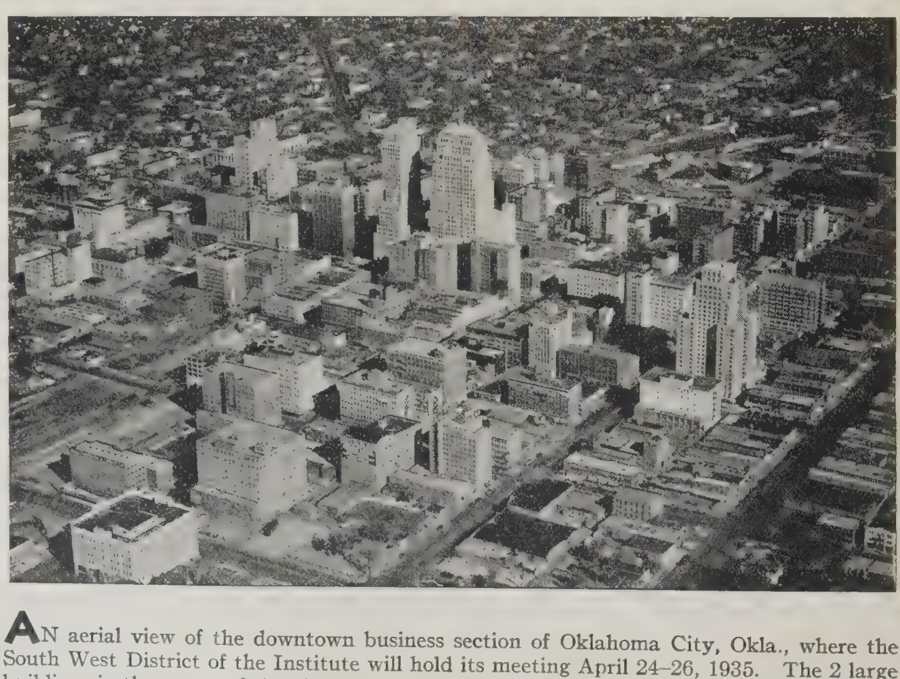
Other articles on specific activities of the E.C.P.D. are contained in this and the 2 preceding issues of ELECTRICAL ENGINEERING, additional articles being scheduled for future issues. This information is presented to members of the Institute in order to keep them acquainted with the progress of the E.C.P.D.

Local E.C.P.D. Meeting Held in New York City

Four eminent engineers discussed the aims and achievements of the Engineers' Council for Professional Development at a meeting of the New York metropolitan sections of the 5 national engineering societies representing the civil, mining and metallurgical, mechanical, electrical, and chemical engineers. The meeting was held on March 6, 1935, in the Engineering Societies Building in New York City. The E.C.P.D. is an agency created and jointly sponsored by these 5 societies and by the Society for the Promotion of Engineering Education and the National Council of State Boards of Engineering Examiners.

The meeting was presided over by Mr. Gano Dunn (A'91, M'94, F'12, past president and life member) president of the J. G. White Engineering Corporation, and recently elected chairman of the board of trustees of Cooper Union. The speakers

Oklahoma City, Scene of a Forthcoming Meeting



AN aerial view of the downtown business section of Oklahoma City, Okla., where the South West District of the Institute will hold its meeting April 24–26, 1935. The 2 large buildings in the center of the picture are, right, the First National Bank building, and left, the Ramsey Tower. The 3-section building just to the right and above the bank building is the Skirvin Hotel, headquarters for the South West District meeting. The program for this meeting was given in ELECTRICAL ENGINEERING for March 1935, page 336–8.

were Dr. C. F. Hirshfeld (A'05) chairman of the E.C.P.D., and chief research engineer, Detroit (Mich.) Edison Company; Gen. R. I. Rees, chairman of the E.C.P.D. committee on professional training, and assistant vice president of the American Telephone and Telegraph Company; and Dean J. W. Barker (M'26, F'30) member of the E.C.P.D. committee on professional recognition, and dean of the school of engineering at Columbia University.

In introducing the meeting, Mr. Dunn referred to the apparent diversity of engineering occupations which have followed in the wake of science and invention, and emphasized the essential unity of all engineers in their methods of attacking problems. Pointing out that the E.C.P.D. rests upon and derives its strength from the whole profession, Mr. Dunn stated that he saw in the E.C.P.D. "the dawn of a professional self-consciousness among engineers, the effects of which on the engineer's status in society and on his satisfactions in life may be profound."

Doctor Hirshfeld discussed the philosophy underlying the relations of an engineer to society, and pointed out that if the engineer makes himself a sufficiently well trained, broad visioned, generally capable person, recognition by the world at large is bound to occur; stating further that the engineer will be recognized in proportion to his ability to serve society broadly and not alone in a narrow technical sense. Doctor Hirshfeld outlined the organization of the E.C.P.D. with its 4 working committees, namely, the committees on student selection and guidance, engineering schools, professional training, and professional recognition, pointing out that it is the purpose of these committees to assist and guide the engineer in achieving the personal development necessary for his recognition by society.

General Rees and Dean Barker outlined the policies of their committees, and told of work which they were doing.

Future AIEE Meetings

South West District Meeting,
Oklahoma City, Okla., Apr. 24–26, 1935

Summer Convention,
Ithaca, N. Y., June 24–28, 1935

Pacific Coast Convention,
Seattle, Wash., Aug. 27–30, 1935

Great Lakes District Meeting,
West Lafayette, Indiana, Oct. 24–25, 1935

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 1936

Summer Convention,
Los Angeles, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Akron, Ohio (date to be determined)

Ambrose Swasey Receives Washington Award

The Washington Award for 1935 was formally presented to Dr. Ambrose Swasey (HM'28) at ceremonies held in Chicago, February 20, 1935. This award "presented annually to an engineer whose work in some special instance, or whose services in general, have been noteworthy for their merit in promoting the public good" was made to Doctor Swasey "for his distinguished contributions as a builder of instruments, institutions, and men."

The Washington Award was founded in 1916 by John Watson Alvord, to be awarded annually by the Western Society of Engineers (Chicago) upon the recommendation of a commission composed of 9 representatives of that society and 2 representatives of each of the 4 national engineering societies representing the civil, mining and metallurgical, mechanical, and electrical engineers.

Doctor Swasey, chairman of the board, The Warner-Swasey Company, Cleveland, Ohio, long noted as a maker of precision machine tools and instruments, is perhaps best known to and beloved among the engineering fraternity for his foresight, humanitarianism, and inspiring leadership. It was his substantial financial backing that led in 1914 to the formation and successful development of The Engineering Foundation "for the furtherance of research in science and engineering, or for the advancement in any other manner of the profession of engineering and the good of mankind."

An outline of Doctor Swasey's career and the many honors that have been accorded to him was presented in ELECTRICAL ENGINEERING for May 1934, page 815, and for November 1934, page 1552. The latter item is a report of the tribute paid to him upon the 20th anniversary of his creation of The Engineering Foundation, and in celebration of his approaching 88th birthday. It is also interesting to note that upon the occasion of his 88th birthday in December, Doctor Swasey received the unusual distinction of having an asteroid, discovered by Dr. Otto Struve, director of Yerkes Observatory, named "Swaseya" in his honor. Doctor Swasey's firm has been the builders of some of the world's greatest telescopes.

Suggestions for Research Projects

The number of requests received for copies of the list of suggestions for research projects prepared by the committee on research of the Institute has been very encouraging in view of the fact that the announcement of the availability of such a list was made only last November in ELECTRICAL ENGINEERING for that month.

For the benefit of those who may not have seen it at that time, it is repeated here.

With the object of stimulating interest in research work, the committee on research of the Institute has collected from electrical engineers in the industry suggestions for research projects suitable for advanced or graduate students and others in the engineering schools who are desirous of undertaking some kind of research work in the electrical engineering field.

A first list of over 100 such research suggestions in 12 branches of electrical engineering has been assembled. A widely varying range of experimental facilities is involved, from the simplest equipment found in any electrical laboratory to highly special facilities which would be available only in a very comprehensively equipped laboratory.

Copies of this list in mimeographed form may be obtained by any member of the teaching staff of an engineering school by merely addressing a request for a copy (or copies) to the committee on research at Institute headquarters, 33 West 39th Street, New York, N. Y.

The committee is planning to issue another list, number 2, early this fall. A copy will be sent to each recipient of the first list.

To Institute Members Planning Trips Abroad

Members of the Institute who contemplate visiting foreign countries are reminded that since 1912 the Institute has had reciprocal arrangements with a number of foreign engineering societies for the exchange of visiting member privileges, which entitle members of the Institute while abroad to membership privileges in these societies for a period of 3 months and members of foreign societies visiting the United States to the privileges of Institute membership for a like period of time, upon presentation of proper credentials. A form of certificate which serves as credentials from the Institute to the foreign societies for the use of Institute members desiring to avail themselves of these exchange privileges may be obtained upon application to Institute headquarters, New York. The members should specify which country or countries they expect to visit, so that the proper number of certificates may be provided, one certificate being addressed to only one society.

The societies with which these reciprocal arrangements have been established and are still in effect are: Institution of Electrical Engineers (Great Britain), Société Française des Electriciens (France), Association Suisse des Electriciens (Switzerland), Associazione Elettrotecnica Italiana (Italy), Koninklijk Instituut van Igenieurs (Holland), Verband Deutscher Elektrotechniker E. V. (Germany), Norsk Elektroteknisk Forening (Norway), Svenska Teknologforeningen (Sweden), Stowarzyszenie Elektrykow Polskich (Poland), Elektrotechnicky Svaz Ceskoslovensky (Czechoslovakia), The Institution of Engineers, Australia (Australia), Denki Gakkwai (Japan), and South African Institute of Electrical Engineers (South Africa).

New Subjects Added at M.I.T. In addition to the recently extended program of graduate study in electrical engineering at Massachusetts Institute of Technology, Cambridge, 3 new subjects are being offered during the current year and a fourth is announced for next year. These are: vibration phenomena and oscillations, engineering electronics, mathematical analysis by mechanical methods, and super high voltage engineering and vacuum electrostatic machinery.

Special Technical Meetings Prove Successful in San Francisco Section

AN innovation in Section meetings modestly introduced last year by the Institute's San Francisco Section has been received with such growing enthusiasm by members in that Section, that an outline of the plan is presented here for the benefit of other Sections that may be interested. This innovation consists of the scheduling of special informal discussion meetings approximately once a month, between the regular Section meetings.

Evolution of the Special Meetings

It has been the experience in San Francisco that when regular Section meetings on more specialized engineering subjects have been held, only those engineers interested in the particular subject will attend. During the last 2 years, therefore, engineering subjects of a more general nature have been scheduled with consequent increase in average attendance. Subsequent adverse comment, however, pointed out that the meetings were getting away from electrical engineering subjects, and that little opportunity was afforded for detailed discussion of specific problems. This led to the innovation of scheduling between the regular Section meetings on general subjects, special technical meetings which consist principally of informal discussions. It is thus possible to have at the regular meetings a well balanced program that will attract a large number of members, and to present at the special meetings more technical information in specialized fields and to afford opportunities for informal round table discussion with other engineers interested in the same problems.

Attendance at the Special Meetings

Although a preliminary survey indicated that only 15 or 20 members of the Section were at all interested in the special technical meetings, it was decided to try them, and the first special meeting was held on February 9, 1934. A record of the results obtained with the special meetings speaks for itself:

Date	Subject	Attendance
February 9, 1934	Decrement Curves for Power Systems	23
March 9, 1934	Communication by Carrier in Cable	24
April 13, 1934	Symmetrical Components	36
May 11, 1934	Electric Corrosion of Pipe Lines	37
October 12, 1934	Synchronous Machines	80
November 9, 1934	Lead Cable Sheath Research	37
January 11, 1935	Overloading Power Transformers	31
February 8, 1935	Elements of Operational Calculus	35
March 8, 1935	Coaxial Communication Lines	31

During 1934, the following topics have been presented at the regular Section meetings: "Survey of Various Television Systems," "Television With Cathode Ray Tubes," "Radium and Its Modern Applications to Science and Technology," "Liquid Dielectrics," "High Voltage Underground and Overhead Cables," "The Modern Physical Conduction of Electricity Through Gases," and "Recent Engineering Developments." Also, a joint meeting with 3 student Branches, and a 50th Anniversary celebration meeting, were held as regular Section meetings. Attendance at the regular Section meetings has been maintained in spite of the special meetings.

It is now difficult to tell which of the 2 types of meetings is the more important, for they seem to serve largely different groups, thereby in effect practically doubling the total attendance per month. Also, it has been found, as expected, that with the exception of a few "regulars" which attend all the meetings, different groups attend the different special meetings.

Selection of Subjects

In selecting subjects, the tendency has been to select some subject which the practicing engineers feel they need to know more about, and then to find a speaker who can lead the discussion and answer questions on that topic. Frequently, a paper or group of papers previously published in Electrical Engineering are made the subject of the meeting. This has been found to help those who do not read many of the published articles, as well as those who, to clarify their own understanding, would like to discuss articles they have read.

No difficulties have been experieneed in obtaining good subjects or good speakers, and it is possible to schedule meetings well in advance. Very little burden devolves upon the committee responsible for arrangements, for many suggestions are received from members as to discussions of detailed subjects desired.

It is obvious that many types of talks can be scheduled for special meetings that would not be suitable for general meetings. In this connection it might be mentioned, however, that particular attempts are made to prevent manufacturers or manufacturers' representatives from using the special meetings as opportunities to give talks with a "sales flavor."

Informality Stressed

Although the regular Section meetings are quite formal, the special technical meetings are most informal; this is believed to be one of the reasons for their success. As money is not available to spend on these special meetings, they are held in power or communication company buildings, or some other place where no charge is made. Advance announcement in the Section's monthly *Bulletin* gives the date, subject, and location of the scheduled meeting, and indicates where members will gather informally for dinner. No dinner reservations are made, and attendance varies with circumstances.

The usual method of procedure at these special meetings is for the chairman to call the meeting to order and introduce the speaker who then runs the meeting. The talks usually are given most informally, and the speaker usually tells the audience to interrupt him when any one has any question, or wants to say anything. This has worked out very well, and with the result that every one, young or old, who is at all interested in doing so, gets an opportunity to be a "doer" rather than just a listener.

Individual and Section Are Benefited

In short, both the individual member and the Section have benefited from these informal discussion meetings. The individual gets more out of his connection with the Institute through enhanced opportunities for actual participation and for getting timely information along definite lines in which he may be interested. From the Section point of view, more is being given to members, the over-all attendance at meetings is improved, and a greater interest in the Institute is created, thus giving the membership committee a supporting incentive.

Related Activities of This Section

Members of the San Francisco Section take a great deal of interest in the numerous activities of this Section, some of which are related to the special meetings. In addition to the regular and special meetings, which are each held once a month, an informal luncheon is held every Tuesday at a special table in the Engineers' Club, which will accommodate 35 members and which is usually filled to overflowing. Consideration also is being given to the scheduling of a certain number of inspection trips, but for fear of having too many activities going on at once, this suggestion has not yet been acted upon.

In addition to the above, the previously mentioned Section *Bulletin* is mailed to members every month. It consists of a (5 by 7 inch) 4-page inexpensively printed pamphlet combining notices of future meetings, reports of past meetings, "personal" items, reports of local committees, references to national activities, and other pertinent information. Although the preparation of this bulletin takes considerable time, it is an effort that has brought great returns.

For the past few years a steadily increasing feeling of friendship among the membership of the Section has been noticed and freer contacts between the more prominent engineers and the younger men have been brought about.

The results of these various activities are regarded as ample compensation for the tremendous amount of work done by the Section's executive committee. Since the activities have expanded, the Section has been fortunate in having an active group on its executive committee. It is felt that this may be due to the particular system for selecting officers adopted by this Section 5 years ago, which requires the rotation of officers so as to insure that all the principal offices are held by men having previous Section experience, and which makes it impossible for a person to hold any particular office for a long time. More of the younger men are thus given Section offices. These offices require considerable work and cannot be considered as purely honorary positions; it is considered vital to Section welfare that they be filled by active men.

A Message to Students of Electrical Engineering

A message to electrical engineering students prepared by the Institute's committee on research follows:

"Research is an activity of vital importance to the electrical industry. Electrical engineering was founded on research, its rapid and extensive development was made possible through the results of research, and research is essential to its further progress. At least 50 per cent of the papers presented before the Institute during recent years are definitely of a research character, under the definition of research, namely, "A systematic investigation of some phenomenon or series of phenomena by the experimental method to discover facts or coördinate them as laws." Incidentally, however, it should be noted that there is always plenty of opportunity for valuable research that does not involve "experimental methods." For example "library research" that is a critical review of existing literature which reports the results of studies and investigations on a given subject may permit crystallizing existing knowledge and facts which can be coördinated into laws.

"Progress in electrical engineering research and, therefore, progress in the electrical art will be greatly influenced by the young engineers coming into the profession. The following resolution passed by the committee on research of the Institute at a recent meeting carries a message to students (and also incidentally to their teachers):

"'It is the opinion of the A.I.E.E. committee on research that, exclusive of immediate problems to be handled by the existing specialists, the general progress of engineering research primarily will depend upon general interest and thorough training of the young engineers in the principles of physics, mathematics, mechanics, and chemistry, including both theoretical principles and experimental technique.'"

A.S.C.E. Appoints Field Secretary

The American Society of Civil Engineers has created the new and important post of field secretary, and has appointed Walter E. Jessup, member of A.S.C.E. and since 1930 editor of *Civil Engineering*, to that position. When *Civil Engineering* was initiated in 1930, Mr. Jessup came to New York from his home in Los Angeles, the intent at that time being that as soon as the character of that publication should be established and he might turn the work over to some one else, he would take on just such duties as have now been defined as for a field secretary. Society finances heretofore had not permitted the expansion then in mind. Two younger men will be selected to assist in the editorial department, and *Civil Engineering* will devote more space to information about society affairs.

Mr. Jessup was born in Pasadena, Calif., May 25, 1888, the son of a civil engineer. He received the degree of bachelor of arts from the University of Southern California in 1910, and that of civil engineer from the University of Wisconsin in 1912, being appointed student assistant in railway engineering while at Wisconsin. He was elected president of the local chapter of Tau Beta Pi in 1912. Following graduation he was engaged in field engineering in connection with the construction of the Los Angeles Aqueduct, the hydroelectric development at Big Creek, Calif., highways for the state of California, and the Salt River project, Arizona, of the U. S. Reclamation Service. In 1917, he was resident engineer on the ballasting and bridge replacement program of a railroad in California and Nevada, following which he was in army service for 2 years, spending 16 months in France as first lieutenant with the 39th Engineers. He now holds a reserve commission as major of engineers.

Following the war, Mr. Jessup entered the employ of a firm of consulting engineers in Los Angeles, and in 1924 opened a consulting office in that city, in partnership with H. Z. Osborne. This partnership was dissolved in 1930 to permit him to take up his duties as editor of *Civil Engineering*. Mr. Jessup joined the Los Angeles Section of the society in 1914, editing its publication, the *A.S.C.E.*, for a number of years, and serving as its president in 1929. He was also a member of the Pasadena Engineers' Club and the Joint Technical Society of Los Angeles, being secretary of the latter organization in 1930. He was one of the founders of the Los Angeles Alumni Club, Tau Beta Pi, serving as its secretary-treasurer for 14 years.

Walter E. Jessup

Student Branch Sponsors Public Meeting

The University of Alabama Branch of the A.I.E.E. located at University, Ala., in connection with the local student branch of the Illuminating Engineering Society, arranged an address to be presented to the public on February 19, 1935. In departing from the usual practice of holding meetings for engineers and engineering students only, it was felt that a service was rendered to the public through the dissemination of information which had been collected by engineers.

The subject selected for this public meeting was "The Science of Seeing," the lecture being delivered by Alston Rodgers, illumination engineer of the General Electric Company. Considerable equipment was available to assist in clarifying the lecture and making it interesting to the public. Approximately 300 persons were present in the university auditorium to hear the lecture.

Electronics and Electron Tubes

Three related publications on theoretical and experimental electronics and electron tube applications, originally intended for educational institutions, are now available to the public. One of these, "Electronics and Electron Tubes" was written by E. D. McArthur of the vacuum tube engineering department of the General Electric Company, in response to requests from schools and colleges for a publication giving, in easily understood language, the fundamentals underlying the vacuum tube, and including simple experiments to illustrate these fundamentals. References are included which enable the reader to delve more extensively into many of the subjects which are treated in this 48 page booklet, $8 \times 10^1/_2$ inches in size. Designated as publication GET-568-A, it may be obtained from the educational section, General Electric Company, Schenectady, N. Y., at a cost of 25 cents.

The other 2 publications, designated GET-566 and GET-620, deal with laboratory experiments on electron tube theory, and on electron tube applications, respectively. The former describes experiments and is intended as a supplement to "Electronics and Electron Tubes," while the latter is a laboratory manual covering a number of fundamental electron tube applications. The 2 booklets are obtainable as a combination priced at 25 cents.

California Pacific International Exposition

The California Pacific International Exposition will open in San Diego, Calif., on May 29, 1935. Officials of the exposition announce that impressive and instructive displays of many leading electrical manufacturing companies, as well as light, power, and communication companies, many already under construction, and many others in various stages of planning and negotiation, will result in an aggregate showing of the electrical industry which will be the most spectacular ever witnessed on the Pacific Coast.

The majority of these exhibits will be housed in the impressive Palace of Electricity, one of the many display buildings erected along the acacia lined Avenue of Palaces, the principal thoroughfare running through the fair grounds. The Palace, 388 x 118 feet, is a low oblong building designed in a modern adaptation of the adobe style of architecture.

The high mesa in the center of historic Balboa Park in San Diego will serve as the setting for the exposition. This was the

September 1, 1935. Mr. Carman worked with the trustees in planning the school as it had been conceived by Allen C. Lewis, the founder, in 1895.

A Reading List for Junior Engineers

A LIST of books recommended for reading by junior engineers has been prepared by a number of eminent men, many of them distinguished in the engineering profession. Previous sections of this list have been published in ELECTRICAL ENGINEERING for December 1934, page 1667, January 1935, page 133, and March 1935, page 345. Two additional sections are published herewith, and others are scheduled to follow in subsequent issues. The complete list includes more than 100 titles.

Systematic reading of worth while books adds breadth and vision to the background of an engineer and should be considered a part of the intellectual development designed to fit the young engineer for full professional recognition. It is suggested that over a period of about 4 years a minimum of about 25 of these books might be selected and read, with the limiting recommendation that the selection made will include at least one book in each classification, preferably in accord with the individual engineer's most vital interests.

Business and Industrial Management

Studies in the Economics of Overhead Costs, J. M. Clark. University of Chicago Press, 1923. Studies of the discrepancies between supply and demand. Unused capacity is the central theme.

The Young Man in Business, Howard L. Davis. Wiley, 1932. Simply written book on vocational guidance by a director of such activities in industry; of particular interest to young people.

Organization Engineering, Henry Dennison. McGraw-Hill, 1931. Well written and shows original observation and analysis. Intended as an over-all picture of the whole problem, rather than as a discussion of specific situations. Intent is to encourage further systematic development of the art and science of organization engineering.

Economic Control of Engineering and Manufacturing, F. L. Eidman. McGraw-Hill, 1931. Purpose of this book is to focus attention on economic aspects of engineering. It presents practical methods and techniques for solution of major industrial problems.

Principles of Industrial Organization, Dexter S. Kimball. McGraw-Hill, 1933. New edition fully revised and containing new material on such subjects as measures of management, mechanization of industry and factory arrangement, and production control.

Business Leadership, H. C. Metcalf. Isaac Pitman, 1931. A series of 25 lectures by various writers on biological, engineering, psychological, industrial, political, and educational problems of management.

Technique of Executive Control, E. H Schell. McGraw-Hill, 1930. Straight thinking applied to the duties and difficulties of the executive, with stimulating questions based upon the problems presented.

Human Nature and Management, Ordway Tead. McGraw-Hill, 1929. Book addressed primarily to the factory manager. Tells what psychology means, giving outline of mechanism of emotions, habits, tendencies, and learning process.

History

Epic of America, James T. Adams. Little, Brown, 1931. An inspiring narrative of the evolution of the American nation.

Century of Progress, edited by C. A. Beard. Harper, 1933. A summary of outstanding events of the last 100 years in American history.

Conquests of Civilization, J. H. Breasted. Harper, 1926. A summary of human progress from the crude beginnings of civilization to the fall of Rome.

Modern Democracies, Viscount James Bryce. 2 volumes, Macmillan, 1924. Analytical summary of general principles of democracies as shown in France, Switzerland, Canada, United States, Australia, and New Zealand.

Europe: A History of Ten Years (1918–1928), R. L. Buell. Macmillan, 1929. An account of the drift of Europe during this time, by the research staff of the Foreign Policy Association. Traces history of Paris peace treaties and the internal development of leading countries and attempts to interpret bolshevism and facism.

Soviet Russia, W. H. Chamberlain. Little, Brown, 1930. Impartial interpretation of happenings in Russia during the 7 years before 1930 during its transition from tsarism to communism. Gives historical background of the revolution and its personalities and discusses the social leveling, cultural and religious questions, and the woman movement.

Historial Evolution of Modern Nationalism, C. J. H. Hayes. R. R. Smith, 1931. Discussion of nationalism as a political philosophy formulated by leaders of thought and opinion, instead of a social process or a popular movement.

Outline of History (new and revised), H. G. Wells. Garden City Publishing Company, 1931. A readable commentary on the life of man from time of the stone age.

site of San Diego's portion of the historic Panama Pacific Exposition in 1915. On this site, many huge exposition palaces already have been completed and the "midway" and amusement park with the "foreign villages" are under construction. The impressive Ford Building, Federal Building, and other buildings are now being erected. It is estimated that the entire exposition, when completed, will represent an investment of more than $16,000,000.

It is reported that the entire U. S. Fleet will make San Diego its headquarters during the period of the exposition, and massed maneuvers of the combined army, navy, and marine air services will be one of the features of the military and naval displays.

Lewis Institute Director Resigns. Information received from Fred A. Rogers (A'06, M'28) dean of engineering and professor of physics and electrical engineering at Lewis Institute, Chicago, Ill., indicates the resignation of G. N. Carman as director of that institute after 40 years of service. The resignation is effective

Physical Society to Meet. The 198th regular meeting of the American Physical Society will be held in Washington, D. C., April 24–27, 1935. The Thursday and Friday sessions will be at the Bureau of Standards, and the Saturday sessions at the National Academy Building. The headquarters' hotel is The Raleigh.

Innovations Introduced at Purdue University. Three announcements of changes affecting teaching for next year at Purdue University, Lafayette, Ind., have been made. One of these is the appointment of Dr. Lillian M. Gilbreth, consulting engineer in management, of Montclair, N. J., as professor of management at Purdue University, effective September 1935. Doctor Gilbreth is recognized as one of the world's most eminent management engineers. The second announcement is the offering of a new curriculum in public service engineeing beginning September 1935, having as one of its major objectives the preparation of engineers capable of dealing with the technological problems of government. The third announcement, also effective September 1935, is the initiating of a combined 6-year course in engineering and law at Purdue University and Indiana University, for those interested in an engineering background for law practice.

Radio Club of America Celebrates 25th Anniversary

Dedicated to the "spirit of good fellowship and the free interchange of ideas among all radio enthusiasts" the Radio Club of America, Inc., has issued a special Year Book in commemoration of its 25th anniversary. Among the names appearing in the roster of present and past leaders of this pioneer club (said to be the oldest radio club in the world) are to be found many long since prominent in the world of radio communication as it is known today, and several now appearing on the roster of active members of the A.I.E.E.

Quoting from opening paragraphs of the Year Book:

"The story of the Radio Club of America begins over a quarter of a century ago, during the really dark ages of the radio art, about 1907. . . . Here we find a group of small boys who, according to the true American spirit, were so interested in flying that they formed the Junior Aero Club of U.S.

"In conjunction with their experiments in aviation, these youngsters had, for some time, also been interested in what was then known as wireless. In fact, the new idea of sending messages without wires had proved itself so fascinating, that they found themselves actually devoting most of their spare time to tinkering with wireless apparatus. There were at this time a

small number of so-called amateur wireless experimenters in and about New York City, so the boys decided to form a new club with wireless as an object."

"Accordingly, . . . a special meeting of the Aero Club, for the purpose of forming a new club, with wireless telegraphy and telephony as its main interest. . .was held at the Hotel Ansonia in New York City on January 2, 1909. . . . Thus, the Junior Wireless Club Limited was founded," and bore that name until October 21, 1911, when it was changed to the Radio Club of America in recognition of its expanding membership and interests.

The Year Book presents a comprehensive outline of the history of the club, lists the major contributions of its members to communication literature, and includes a roster of members and of past and present officers. Copies of the Year Book are said to be available at the club's executive headquarters, 11 West 42nd Street, New York, N. Y.

Among the present and past officers of the Radio Club of America are noted the following members of the Institute:

Ernest V. Amy (A'19, M'28) consulting engineer, Amy, Acebes and King, Inc., New York, N. Y.
Carl Dreher (A'23, F'33) sound director, RKO Studios, Inc., Los Angeles, Calif.
George J. Eltz, Jr. (A'21) co-owner, Continental Sales Company, Hartford, Conn.
Lawrence C. F. Horle (A'20, M'22) consulting radio engineer, Newark, N. J.
Harry W. Houck (A'21) consulting engineer, Camp Hill, Pa.
Theophilus Johnson, Jr. (A'18) commercial engineer, General Electric Company, Schenectady, N. Y.
Ralph H. Langley (M'34) consulting engineer, New York, N. Y.
Louis G. Pacent (M'18, F'30) president and technical director, Pacent Engineering Corp., New York, N. Y.

United Engineering Trustees, Inc.

The Joint Engineering Organizations

United Engineering Trustees, Inc., organized in 1904, is now the joint agency of the 4 national societies representing the civil, mining and metallurgical, mechanical, and electrical engineers. It is organized in 3 departments, namely, the administrative department, The Engineering Foundation, and the Engineering Societies Library.

The administrative department manages the Engineering Societies Building and all trust funds placed in the hands of the United Engineering Trustees, Inc. The Engineering Foundation, founded by Ambrose Swasey (HM'28) in 1914, is entrusted with the expenditure of the income from endowments and other funds, its present preferred activity being engineering research. The Engineering Societies Library is a free public library which, with its numerous activities, is operated for users at a distance, as well as for those who visit its rooms in the Engineering Societies Building.

Inasmuch as a brief résumé of the organization of the United Engineering Trustees, Inc., and the 3 departments enumerated above, was given in ELECTRICAL ENGINEERING for April 1934, page 632, further details will not be given here. In the accompanying article will be found announcements of elections and abstracts of the annual reports of these organizations.

Election of United Engineering Trustees, Inc., Held

At the annual meeting of United Engineering Trustees, Inc., which was held in the Engineering Societies Building, New York, N. Y., January 24, 1935, officers to serve for 1935 were elected. H. V. Coes was reëlected president, to serve for the period ending at the annual meeting in October 1935. G. L. Knight (A'11, F'17) was reëlected first vice president, also serving until October 1935. H. G. Moulton was elected second vice president to serve for the period ending October 1936. Also, John Arms was elected secretary, C. P. Hunt, treasurer, and O. E. Hovey, assistant treasurer, all to serve until October 1935.

The names of the members of the board of trustees of the United Engineering Trustees, Inc., are given in the following tabulation. Those members having terms expiring in October 1935 and October 1936 hold over from previous elections. Those shown having terms ending in October 1937 and October 1938, took office at the January 24, 1935, meeting, as a result of appointment or reappointment.

Terms expiring in October 1935	
C. W. Hudson	A.S.C.E. representative
George A. Easley	A.I.M.E. representative
Harold V. Coes	A.S.M.E. representative
H. P. Charlesworth (M'22, F'28 and junior past president)	A.I.E.E. representative
Terms expiring in October 1936	
John P. Hogan	A.S.C.E. representative
H. G. Moulton	A.I.M.E. representative
D. R. Yarnall	A.S.M.E. representative
H. R. Woodrow (A'12, F'23)	A.I.E.E. representative
Terms expiring in October 1937	
Otis E. Hovey	A.S.C.E. representative
William L. Batt	A.S.M.E. representative
Terms expiring in October 1938	
A. L. J. Queneau	A.I.M.E. representative
G. L. Knight (A'11, F'17)	A.I.E.E. representative

In accordance with the 1934 revision of the by-laws, the terms of officers and members of the board of trustees have been changed so as to expire each year on the first of October, instead of in the following January. Also, the terms of members of the board of trustees are being changed from 3 year to 4 year terms. During the period of transition to the 4 year term basis, some of the societies will elect members for 3 year terms and others for 4 year terms. Starting with the official year beginning October 1, 1938, all elections will be for 4 year terms. In 1935, 1936, and 1937, the civil and the mechanical engineers shall each appoint or elect one trustee for a 3 year term, and the mining and electrical engineers one trustee each for a 4 year term. In 1938, the civil and mechanical engineers shall each appoint or elect one trustee for a 4 year term, but the mining and electrical engineers shall not appoint or elect any trustee. In 1939 and 1940 every founder society shall appoint or elect one trustee for a 4 year term. Thereafter, as each term is completed, the appropriate founder society shall appoint or reappoint, elect or reëlect, as provided in these by-laws, a trustee for the succeeding 4 year term.

This means that for the 4 year term beginning October 1, 1938, the terms beginning October 1, 1942, and every fourth year thereafter, the mining and electrical engineers will not appoint or elect any trustee. For the 4 year term beginning October 1, 1941, and every fourth year thereafter, the civil and mechanical engineers will not appoint or elect any trustee.

COMMITTEES APPOINTED

President Coes appointed the following committees: finance committee, G. L. Knight (A'11, F'17) *chairman*, Otis E. Hovey, H. G. Moulton, W. L. Batt, and H. V. Coes, *ex-officio;* real estate committee, H. R. Woodrow (A'12, F'23) *chairman*, John P. Hogan, A. L. J. Queneau, H. V. Coes, and the secretaries of the 4 societies, George T. Seabury, A. B. Parsons, C. E. Davies, and H. H. Henline.

Election Held by Engineering Foundation

The board of directors of The Engineering Foundation at its annual meeting held in the Engineering Societies Building, February 21, 1935, reëlected as its chairman H. P. Charlesworth (M'22, F'28, and junior past president) assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y. Mr. Charlesworth is a representative of the A.I.E.E. on the board. He was previously elected chairman, as announced in ELECTRICAL ENGINEERING for January 1935, page 134, to fill the unexpired term caused by the death of George W. Fuller. D. Robert Yarnall, a representative of The American Society of Mechanical Engineers, and a member of the firm Yarnall-Waring Company, Philadelphia, Pa., was reëlected vice chairman. The executive committee is composed of these 2 members, together with the following 3 persons: J. V. N. Dorr, member-at-large, president, The Dorr Company, engineers, New York, N. Y., and a representative of the American Institute of Mining and Metallurgical Engineers; Edwards R. Fish, member-at-large, chief engineer, boiler division, Hartford Steam Boiler Inspection and Insurance Company, Hartford, Conn., and a representative of The American Society of Mechanical Engineers; and O. E. Hovey, consulting engineer, American Bridge Company, New York, N. Y., and a representative of the American Society of Civil Engineers. Dr. A. D. Flinn was reëlected director and secretary.

The officers and executive committee of

Engineering Foundation are elected by The Engineering Foundation board from among its own members. The Engineering Foundation board is itself elected by the board of trustees of United Engineering Trustees, Inc. Members of The Engineering Foundation board who were elected at the meeting of United Engineering Trustees, Inc., on January 24, 1935, and who serve for terms of 4 years expiring at the annual meeting in 1938, or upon expiration of terms as trustees are as follows:

Otis E. Hovey, trustee, to succeed Arthur S. Tuttle, A.S.C.E.
A. L. J. Queneau, trustee, to succeed R. M. Roosevelt, A.I.M.E.
Langdon Pearse, nominated by A.S.C.E. to succeed Otis E. Hovey
E. DeGolyer, nominated by A.I.M.E. to succeed himself
Frederick M. Becket, to succeed George Gordon Crawford, member-at-large
Harold V. Coes, *ex-officio*, president, United Engineering Trustees, Inc.

The complete membership of The Engineering Foundation board, consisting of the above mentioned newly elected members, and the members holding over from previous elections, is given in the following list:

Four Trustees of U.E.T. Inc.		
Otis E. Hovey	A.S.C.E.	1937
A. L. Queneau	A.I.M.E.	1938
D. Robert Yarnall	A.S.M.E.	1936
H. P. Charlesworth (M'22, F'28, and junior past president)	A.I.E.E.	1935
Eight Members Nominated by Founder Societies		
George E. Beggs	A.S C.E.	1935
Langdon Pearse	A.S.C.E.	1938
George D. Barron	A.I.M.E.	1936
E. DeGolyer	A.I.M.E.	1938
Albert E. White	A.S.M.E.	1935
W. H. Fulweiler	A.S.M.E.	1936
C. E. Skinner (A'99, F'12, and past president)	A.I.E.E.	1935
W. I. Slichter (A'00, F'12, and national treasurer)	A.I.E.E.	1936
Three Members-at-Large		
Frederick M. Becket		1938
J. V. N. Dorr		1935
Edwards R. Fish		1935
Ex-officio, President, U.E.T., Inc.		
Harold V. Coes		

The new chairman of Engineering Foundation, H. P. Charlesworth, was also elected as the Foundation's representative on the executive board of National Research Council.

At this meeting, the chairman was authorized to appoint a committee of 3 to consider the subject of platform and general program for the Foundation, utilizing the results of previous studies, and if practicable, reporting to the board in advance of the next meeting. Subsequently the chairman appointed the following to this committee: Otis E. Hovey, chairman, D. Robert Yarnall, and H. P. Charlesworth.

Annual Report Issued by United Engineering Trustees, Inc.

The annual report of United Engineering Trustees, Inc., for 1934 has been submitted by its president, Harold V. Coes. In this report, it is pointed out that properties for which the corporation is responsible (real estate at cost, funds at book value, and library as appraised) total nearly $4,000,000. The aggregate value of investments on December 31, 1934, was $1,338,852.98, and the market value was $1,236,677.25.

As previously announced, Dr. Alfred D. Flinn resigned as secretary (although continuing as director and secretary of The Engineering Foundation) general manager John Arms being elected to the office of secretary in addition to holding that of general manager. This change necessitated other changes in the methods of carrying on the corporation's activities.

During the year, improvements were made in the Engineering Societies Building, desirable changes were made in the by-laws, the arrangements for fire insurance coverage for the building were changed so as to result in appreciable saving, and other work necessary for the maintaining of the Engineering Societies Building, and the handling of the funds entrusted to United Engineering Trustees, Inc., was carried on. The trustees found the time inopportune to restore the salary cuts in effect for the staff, so that this economy remains in the 1935 budget.

A summary of the report for 1934 of the finance committee of this corporation appears in table I.

Table I—Summary of U.E.T. Finance Committee Report for 1934

Operation of Building		
Gross Operating Revenue	$85,160.11	
Less Operating Expenditures	93,852.96	
Net Operating Loss	8,692.85	
Uncollectable Accounts Written Off*	2,916.00	
Net Decrease for Year	11,608.85	
Transfer of Revenue to Depreciation and Renewal Fund	0.00	
Net Decrease for Year	11,608.85	
Credit Balance in Activity Account Jan. 1, 1934	13,276.08	
Credit Balance in Activity Account Dec. 31, 1934		$1,667.23
Operation of Library		
Maintenance Revenue	$40,444.68	
Maintenance Expenditures	39,398.01	
Credit Balance for year 1934	1,046.67	
Transferred to Search Bureau	771.03	
Net Credit Balance for year 1934	275.64	
Credit Balance from previous year	3,422.19	
Credit Balance Dec. 31, 1934		$3,697.83
Service Bureau Revenue	$7,766.78	
Service Bureau Expenditures and Adjustments	8,537.81	
Debit Balance (Deficit)	771.03	
Transferred from Library	771.03	
Balance in Activity Account for year 1934	0.00	
Balance in Activity Account Dec. 31, 1934	0.00	0.00
Total net operating credit balance cumulated to Dec. 31, 1934		$5,365.06
Funds and Property		
Funds held by U.E.T., Inc., Dec. 31, 1934 (book value)		
Henry R. Towne Engg. Fund		$50,000.43
** Combined Fund: including		
Depreciation and Renewal	$332,443.80	
General Reserve	0.00	
Engineering Foundation	783,101.21	
Library Endowment	174,544.32	
Edward Dean Adams	100,000.00	
	$1,390,089.33	
Less deferred charge representing net loss from sale of securities from Dec. 31, 1929 the date of establishment of the Combined Fund to Dec. 31, 1934	94,905.46	1,295,183.87
Real Estate, cost to Dec. 31, 1934		$1,987,793.92
Operating Cash	$6,297.97	
Petty Cash	250.00	6,547.97
Accounts Receivable		1,261.61
Library as appraised for fire insurance		480,800.00
Total		$3,821,587.80
John Fritz Medal Fund (Custodian)		3,500.00
		$3,825,087.80

* Personnel Research Federation, $2,901.00; halls revenue, $15.00; total, $2,916.00.
** A group of funds managed as if one for convenience and economy in investment transactions.

Annual Report Issued by Engineering Foundation

The annual report of The Engineering Foundation for 1934 has been submitted by H. P. Charlesworth (M'22, F'28, and junior past president) chairman of The Foundation, and Dr. Alfred D. Flinn, its director. The Engineering Foundation was founded by Ambrose Swasey (HM'28) in 1914; Doctor Swasey has made 3 bequests to Foundation, totaling $750,000.

In the report it is shown that the capital

fund of The Engineering Foundation consists of endowments having a total book value on December 31, 1934, of $882,000, and the E. H. McHenry bequest, in the hands of executors during the lives of 2 beneficiaries, appraised in 1931 at approximately $400,000. During 1934, the income from the endowment, temporary investment of income balance, and minor items, totaled $44,061.38; and expenditures for research projects, promotion of research, and administrative expenses totaled $33,482.99. This excess of income over expenditures during 1934 resulted in an increase of balance from $11,202.75 to $21,781.14.

The following brief summary of activities during 1934 was given:

"Activities in 1934 included investigations of concrete and reinforced concrete arches, earths and foundations, and plastic properties of concrete, in the civil engineering field; critical review of the world's literature on alloy irons and alloy steels since 1890, and barodynamic research, both sponsored by the American Institute of Mining and Metallurgical Engineers; in coöperation with committees of The American Society of Mechanical Engineers, studies of effects of temperature on properties of metals, cutting of metals, thermal properties of steam, mechanical springs, riveted joints, and wire rope; under sponsorship of the American Institute of Electrical Engineers, an electric welding research on pure iron electrodes. Assistance was given also to Engineers' Council for Professional Development, Personnel Research Federation, and an investigation of The Engineering Index."

American Engineering Council

A.E.C. Reports From Washington

FOLLOWING are excerpts from the current news letter released by American Engineering Council, the "Washington Embassy" of engineers, which appear to be of particular interest to members of the Institute:

Procedure as to Legislation

With so much of engineering interest at stake in the current session of Congress, it seems timely to summarize the policies and methods followed by Council in legislative matters. The staff has for its guidance:

1. Policies adopted by the assembly and administrative board at annual meetings.
2. Advice on new matters from special and standing committees.
3. Precedent of several years on matters which do not require new rulings.
4. The viewpoint of public interest as a fundamental reason for participating in legislative activities.
5. The corollary viewpoint of advancing the economic status of the profession.

The factors of public interest and the status of the profession are closely related in problems constantly arising in connection with the federal program, due to the extraordinary relation of government to business at present. Competent engineers must be employed where engineers belong if the public interest is to be protected against faulty planning and wasteful execution.

Although the "Washington Embassy" of engineers may not jump into drastically new lines of action in the name of the profession without due consultation and approval, it is not hemmed in by ponderous procedure. The precedent set on past work, recognized as in the interest of the profession, gives sufficient latitude for quick action on immediate, practical steps and leaves only the long-range phases for more deliberate action.

Legislation which Council follows for engineers includes the following general categories:

1. *Construction.* Federal appropriations and administrative machinery for construction. (The work-relief bill.)
2. *Development of Industries.* Amendments to the National Industrial Recovery Act, new patent legislation, etc.
3. *Development of Natural Resources.* Bills relating to water power, navigation, reclamation, soil erosion control, surveys and maps, and similar public activities wherein the engineer serves in the development of "our national plant."
4. *Engineers' Welfare.* General legislation in the field of unemployment insurance, old-age pensions, etc; bills such as civil service measures, engineers' compensation on federal and relief work, etc., more directly affecting the engineer.

Scores of bills under each of the above headings are under consideration. With its limited staff Council is obliged to concentrate on those of the greatest importance to the profession. Where needed, information and arguments are presented to Congressional committees in open hearings or otherwise. Council fills frequent requests from federal agencies setting up programs along engineering lines, for information as to features of concern to the profession. The public affairs committee and its subcommittees are sent copies of important bills and documents and are kept generally informed.

Work Relief Bill

Council has been following the federal work relief bill in Congress, and has been coöperating with some of the planners of this bill. It is pointed out that jobless engineers are at a disadvantage in seeking placement under the program until it is revealed just which agencies will handle the various projects; present steps may include registration with the nearest U.S. employment office, securing of political endorsements from county chairmen upward, filing applications with federal agencies in Washington or in field offices, and taking civil service examinations.

Survey of the Engineering Profession

Work is being carried forward on the survey of the engineering profession being made by the U. S. Department of Labor in coöperation with A.E.C. and the national and local engineering societies. An item on this census of engineers was given in ELECTRICAL ENGINEERING for December 1934, page 1677, with shorter items in the January and February 1935 issues, pages 135 and 252, respectively. The list of engineers to whom the questionnaires will be sent has now been compiled, this work having taken longer than expected due to the fact that the engineering societies coöperated so well that a list of upward of 170,000 names has been compiled, instead of the expected list of 100,000. This work has been carried on with the assistance of 12 relief workers in New York City, and it is expected that the questionnaires will be sent out soon. All members receiving these are urged to fill them out and return them promptly, as the survey will be valuable in any analysis of the status of members of the engineering profession.

Other Items

The plan for public affairs committees of Council in each locality (see ELECTRICAL ENGINEERING for February 1935, page 251) may be accelerated in cities having sections of national engineering societies. The sections may appoint representatives on a central committee to handle matters of joint interest. Also, considerable interest in Council's new membership plan has been shown by several local societies.

The National Bureau of Economic Research in whose work A.E.C. is a coöperating agency, reported noteworthy progress and good financial condition at its annual meeting in February. A number of studies and reports relating to engineering and industry have been made by this bureau. Detailed information may be secured by writing the bureau at 1819 Broadway, New York, N. Y.

The holding company bill now before Congress, as phrased at present, tends to extend federal jurisdiction over the practice of engineering under contract with utility firms, according to a resolution by the American Institute of Consulting Engineers, asking Council to intervene.

L. W. Wallace, formerly executive secretary of A.E.C., and during the past year vice president of the W. S. Lee Engineering Corporation, located at Washington, D. C., is now in Chicago, Ill., as director of equipment research for the Association of American Railroads.

The office of the American Engineering Council, at 744 Jackson Place, Washington, D. C., will gladly supply material to individuals wishing to give talks on what A.E.C. is doing for the engineer. It also will supply, upon request, copies of the minutes of the secretaries' conference and of the symposium on federal activities presented at the annual meeting of A.E.C., which was reported in ELECTRICAL ENGINEERING for February 1935, page 251–3.

According to a recent newspaper account

which credits the National Society of Professional Engineers with starting a movement to call the operators of locomotives "engine men" rather than "engineers," Casey Jones is rotating in his grave. The story neglects to say that Council has supported this nomenclature for a good many years and that federal classifications consequently have noted the change long before now.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

CORRECTION—Figures 2 and 3 in the "Letter to the Editor" by E. H. Nelson and Sidney Rock entitled "Over-compounded D-C Generators in Parallel Without an Equalizer" in the March 1935 issue of ELECTRICAL ENGINEERING, page 347–8, should have been interchanged. In further explanation of the text, the point on these 2 reproductions of oscillograms at which the equalizer was opened is about $^1/_4$ inch from the left-hand side, and the point at which the equalizer was closed is at the sharp break in the curves near the middle.

An Engineer's Thought on the Economic Scene

To the Editor:

The following refers to the addresses on "What Place the Engineer in the Changing Economic Scene?" by Dr. Virgil Jordan and Col. W. T. Chevalier, published in ELECTRICAL ENGINEERING for November 1934, page 1546–51:

Doctor Jordan, if I understand him correctly, offers no explanation and suggests no remedy for our present economic chaos. He confuses the economic with the financial aspects in a quite orthodox fashion. Colonel Chevalier at least ventures to express the pious hope that our next generation will learn to put a premium on creation of wealth rather than acquisition of wealth. Just why we should wait for the next generation is not quite clear.

At present there is an analogy going around, which I have not seen in print so far. A private water company was formed. It employed laborers on the condition that for every gallon of water they put into the company's storage tank, they, the laborers, received one gallon. The laborers sold their surplus water or traded it for goods they needed and all was well. But suddenly the company found their tank full and naturally enough laid off all their help. The laborers were told that when they had bought enough water from the company, they would be put back to work again and prosperity would return. The laborers told the company that they had nothing and could buy no water until they got back to work.

A 2 weeks' intermission followed, while the company officials cogitated and ruminated. Finally it was decreed that an advertising specialist should be called in. After making a careful detailed analysis of the situation, he concluded that advertising was the remedy. Tell the folks about your wonderful water. And the tank stayed full, except of course for the fee of this specialist. Etc., ad libitum.

In other words, the public works programs, the housing plans, etc., can accomplish nothing as long as they are to be self-liquidating, which means that the consumers (the workers) are to foot the bill. When the federal government gets ready to start extensive projects to be paid for out of income and inheritance taxes on the higher and highest brackets, i. e., to be taken from the water storage tank, then things will begin to move and will stay moving. That will be fine for business, but not so good for the financiers. This is production for use and it is the only way out. To fit this into the existing order so as to produce the least dislocation of essential functions is the real problem. Electrical engineers interested in transient phenomena may well try their hands at this and let us hear from them. Engineers ought to be interested in social-economic problems and ELECTRICAL ENGINEERING ought to be a proper forum.

Very truly yours,

B. F. JAKOBSEN (A'09, M'13)
(Consulting Engineer, Central Building, Los Angeles, Calif.)

Reignition of an Arc at Low Pressures

To the Editor:

In a recent "Letter to the Editor" (ELECTRICAL ENGINEERING for December 1934, pages 1679–80) R. C. Mason criticizes the theory of the transition from a glow discharge to an arc proposed by us in a paper "Reignition of an Arc at Low Pressures" (ELECTRICAL ENGINEERING, volume 53, July 1934, pages 1081–5).

Mr. Mason claims that the data show that it is impossible for a sufficiently high electric field to be produced in the abnormal glow discharge to produce "field currents" from the cathode. He assumes that a field of 2×10^7 volts per centimeter is necessary to produce such field currents. This figure is correct for tungsten which has been very carefully outgassed in a very high vacuum. However, if tungsten or any other metal is used which has not been outgassed, then field currents will appear at about 10^6 volts per centimeter. Obviously the latter condition obtains in a glow discharge.

Mason further assumes that the length of the cathode drop remains constant as the current is increased, so that an abnormal cathode drop is produced. This is not true. The field increases at the cathode primarily because the region of the cathode drop diminishes and thus produces a greater field at the cathode.

Only a very small amount of impurity on the cathode is necessary to act as a trigger action in the transition from a glow to an arc. This small amount can produce an excess of electrons from the cathode at that spot and these electrons due to ionization produce the high field necessary. Since this effect is cumulative, only some kind of a trigger action is necessary to start it. The theory is presented more in detail in "Cathode Drop in Arc Discharges" by S. S. Mackeown (ELECTRICAL ENGINEERING, volume 51, June 1932, page 386–8).

While it is true that there is not sufficient experimental data to give a good quantitative check of this theory, nevertheless the theory is consistent with all quantitative data that are available.

Simple energy considerations show that, if a high field does exist in the cathode drop of an arc, then that field must be produced during the transition from a glow discharge to an arc. It is only during a transition from a high to a low cathode drop that the high energy density in the cathode drop of an arc can be established. If for any reason this energy is dissipated, it is necessary for the arc to change to a glow discharge before this high energy density at the cathode can be reëstablished.

Very truly yours,

S. S. MACKEOWN (A'27, M'34)
(Asst. Prof. of Elec. Engg., Calif. Inst. of Tech., Pasadena)

J. D. COBINE (Enrolled Student)
(Instructor in Elec. Engg., Harvard Univ., Cambridge, Mass.)

Why Use Vectors and Complex Notation?

To the Editor:

Quite recently an important electrical periodical has published a discussion of a-c vectors and the use of complex quantities. Many such presentations of the use of complex notation in a-c studies are confusing to students and it appears that this is partly due to authors failing to mention explicitly the fundamental ideas that form the foundation of the engineering use.

A development of the subject that is simplified to an extreme may be suggested as follows. It is only the sketchiest sort of outline that is offered here and the reader must complete the story. In fact, an effort has been made to give in this outline only those basic principles that are in general most neglected.

Alternating voltages and currents are of sinusoidal form, and so a voltage (for instance) whose maximum value is E_m may be written as a function of time

$$e = E_m \cos \omega t \quad (1)$$

Such a sinusoidal voltage, and *only* one that is sinusoidal, may be represented by a vector in the following manner: A vector of length E_m rotates with an angular velocity ω and its projection on a fixed axis—with which it always makes an angle ωt—is equal to $E_m \cos \omega t$. See figure 1. With this understanding a vector may represent the voltage at all times, for at any particular instant its projection on the axis is equal to the instantaneous value of the voltage e. The voltage is not the vector, but only the projection of the vector, and vectors are used because it is easier to speak of the vector voltage E than to write equation 1.

It is mathematically expedient to use complex notation, and to measure "real" numbers along the reference axis of figure 1, and to measure "imaginary" numbers along an axis at right angles to it. The vector of voltage is then revolving in the "complex plane" as in figure 2 and at any instant its "real" component is the instantaneous value of voltage e as in equation 1. Hence it is only the "real" component of the vector that has an electrical meaning.

Complex notation is introduced for convenience only, because it is useful mathematically. We wish to add vector quantities (as 2 voltages, or 2 currents) and to divide (as a voltage by a current), because it is expedient to add and to divide vectors instead of computing with the instantaneous values given by equation 1. It happens that the addition of voltage vectors, according to the rule for addition set forth in algebra of complex quantities, gives a resultant vector which represents a voltage that is the sum of the 2 component voltages. That is to say, if e_1 be added to e_2 where

$$e_1 = E_{1m} \cos \omega t$$
$$e_2 = E_{2m} \cos (\omega t + \theta)$$

the actual resultant voltage is

$$e_3 = e_1 + e_2 = E_{1m} \cos \omega t + E_{2m} \cos (\omega t + \theta) \quad (2)$$

The rule for adding complex quantities is, by definition,

$$(a + jb) + (c + jd) = (a + c) + j(b + d)$$

and if the voltage vectors are added according to this rule the complex sum is a vector E_3 which properly represents the voltage e_3 because its real part is always equal to the

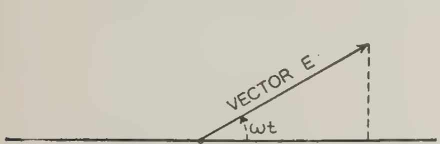


Fig. 1

sum of the real parts of its components and it therefore satisfies equation 2. The addition may be done graphically.

In an ordinary electric circuit a voltage $e = E_m \cos \omega t$ will produce a current $i = I_m \cos (\omega t - \phi)$. This is established experimentally. There is no simple relationship between these quantities, but there is a very simple one, called impedance, between their vectors. For if we represent the voltage by a vector E, and the current by a vector I, those vectors will be rotating at the same velocity ω, and a constant angle ϕ will always separate them. When the vectors are represented by complex quantities one may express this relationship by saying that the voltage "divided" by the current is a constant, and the division is performed according to the rule of complex algebra which says

$$\frac{E}{I} = \frac{E_m/\underline{j\omega}}{I_m/\underline{j\omega - \phi}} = \frac{E_m}{I_m} \underline{/j\omega - (j\omega - \phi)}$$
$$= \frac{E_m}{I_m} \underline{/\phi} = Z \quad (3)$$

This constant ratio is then called "impedance." It is worthy of note that the usual concept of impedance has meaning only in terms of vectors. This is the chief justification of the use of complex quantities in electrical engineering, for without such a system the job of finding the current which would result from a given voltage would not be the simple computation that it is.

Another approach which is available for more mathematically minded students would begin by writing the instantaneous voltage as

$$e = E_m \cos \omega t = E_m \frac{\epsilon^{j\omega t} + \epsilon^{-j\omega t}}{2}$$
$$= \frac{1}{2} (E_m \epsilon^{j\omega t} + E_m \epsilon^{-j\omega t}) \quad (4)$$

The voltage is therefore half the sum of 2 quantities which may be identified as vectors rotating in the complex plane, and since the quantities are conjugate the vectors are of equal magnitude but rotate in opposite directions. In the same way, current is

$$i = \frac{1}{2} (I_m \epsilon^{j(\omega t - \phi)} + I_m \epsilon^{-j(\omega t - \phi)}) \quad (5)$$

The ratio of the vectors with angular velocity $+\omega$ is

$$\frac{E_m \epsilon^{j\omega t}}{I_m \epsilon^{j(\omega t - \phi)}} = \frac{E_m}{I_m} \epsilon^{j\phi} = Z \quad (6)$$

and this is identical with the impedance of equation 3. The ratio of the vectors with angular velocity $-\omega$ is similarly

$$\frac{E_m}{I_m} \epsilon^{-j\phi} \quad (7)$$

and this is the conjugate of impedance as defined above. To handle a-c problems in a simple manner, then, proceed as follows: Discard the conjugate vectors of equations 4 and 5 and write

$$\left.\begin{aligned} E &= E_m \epsilon^{j\omega t} \\ I &= I_m \epsilon^{j(\omega t - \phi)} \end{aligned}\right\} \quad (8)$$

with the convention that the voltage and current are the *real parts only* of the vectors. The usual concept of impedance is the result, as in equation 6, and it is unnecessary to carry through the conjugate impedance of equation 7. But when the answer is obtained it must be interpreted in accord with the convention specified.

Many other presentations will doubtless be found equally good or better (for a good engineering treatment see "Differential Equations for Electrical Engineers," by P. Franklin; John Wiley and Sons, 1933) but there is one matter which is seen so often in print that it may deserve special mention. It has to do with the definition of j. The symbol j, we often read, is defined as an operator that rotates a vector through 90 degrees, and $j \cdot j \cdot E$ leads E by 180 degrees and since the magnitude is unchanged it equals $-E$. These operations are by definition of j and are irreproachable. But j in such a case is not a number; it is a symbol of operation, for it has been so defined, and one cannot take the square root of a symbol of operation. While it is perfectly true that

$$j \cdot j \cdot E = j^2 E = -E$$

it is too naïve to say therefore

$$j^2 = -1 \text{ and } j = \sqrt{-1} \quad (9)$$

A similar disregard for definition could lead one to say that

$$\frac{d}{dx}\frac{d}{dx} \sin x = \frac{d^2}{dx^2} \sin x = -\sin x$$

and it therefore follows that

$$\frac{d^2}{dx^2} = -1 \text{ and } \frac{d}{dx} = \sqrt{-1} \quad (10)$$

Of course the difference between equations 9 and 10 is that by universally accepted definition and notation the former is true

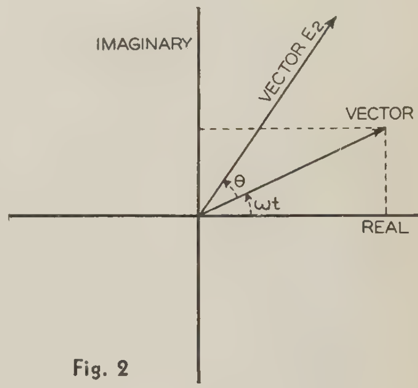


Fig. 2

and the latter is not. But the methods of derivation of the 2 equations are equally erroneous, for in each case a symbol of operation has been treated as if it were a number. To derive equation 9 properly, adopt the following *definition* of multiplication of complex quantities:

$$(a + jb)(c + jd) = (ac - bd) + j(ad + bc) \quad (11)$$

Then let $a = c = 0$ and $b = d = 1$, and one finds $j1 \cdot j1 = -1$. If by convention the symbol j is written to mean the number $j1$, one may now proceed to equation 9 with complete rigor by application of the definition of square root. It is essential to note that j (apart from the agreement to designate $j1$ by this symbol) is not itself a number and does not equal $\sqrt{-1}$. Thus the use of the symbol j in $(a + jb)$ may be said to be a useful shorthand notation for "the ordered pair of real numbers a and b." In fact, a careful approach to the study of complex quantities is by way of ordered number pairs. (An excellent discussion of complex quantities appears in "Pure Mathematics," by G. H. Hardy; Cambridge University Press, 1925.)

This is not the hair-splitting quibble that it may seem, for in the absence of a definition of multiplication such as is supplied by equation 11 there is no way provided by mathematics to multiply together complex quantities. Should this not be clear it will become so if one will start with the formulation of the number system and review the

definitions of multiplication. It is perhaps unreasonable to expect a student of elementary engineering to comprehend the "foundations of arithmetic," but his lack of familiarity with mathematical modes of thought does not justify confusing him with loose statements for the sake of a specious simplicity.

Very truly yours,

Hugh Skilling (A'28, M'34)
(Dept. of Elec. Engg., Stanford University, Calif.)

H. M. Bacon (Nonmember)
(Dept. of Mathematics, Stanford University, Calif.)

Loading a Bank of Dissimilar Transformers

To the Editor:

In the article by J. A. Bock on the "Loading a Bank of Dissimilar Transformers" published on pages 1597–8 of the December 1934 issue of Electrical Engineering, the first fundamental equation $I_a = -j\sqrt{3}\, I_A$ is incorrect for the assumptions made. In spite of this fact, however, his equation 11 is right. To correct this mistake and clarify whatever misleading notions that may be derived from the faulty equation, is the purpose of this letter. The notations used by Mr. Bock in his article will be adopted here. Furthermore, let

$\check{Z}_A = R_A + jX_A$
$\check{Z}_B = R_B + jX_B$
$\check{Z}_C = R_C + jX_C$

$\check{I}_d$ be the direct sequence current in the windings of the transformers
$\check{I}_0$, the zero sequence current in the windings of the transformers

Under the assumption that $I_a = I_b = I_c$ (see figure 1) we get

$\check{I}_A = \check{I}_d + \check{I}_0$
$\check{I}_B = \alpha^2\check{I}_d + \check{I}_0$
$\check{I}_C = \alpha\check{I}_d + \check{I}_0$

The line currents

$\check{I}_a = \check{I}_B - \check{I}_C = -j\sqrt{3}\,\check{I}_d$
$\check{I}_b = \alpha^2\,\check{I}_a$
$\check{I}_c = \alpha\,\check{I}_a$

Therefore

$$0 = N_A\check{E}_A' + N_B\check{E}_B' + N_C\check{E}_C' - [(\check{I}_d + \check{I}_0)\,\check{Z}_A + (\alpha^2\check{I}_d + \check{I}_0)\check{Z}_B + (\alpha\check{I}_d + \check{I}_0)\,\check{Z}_C]$$

Hence If $E_A' = E_B' = E_C'$ we get

$$I_0 = \frac{\check{E}_A'(N_A + \alpha^2 N_B + \alpha N_C)}{\check{Z}_A + \check{Z}_B + \check{Z}_C} - \dot{I}_d\,\frac{\check{Z}_A + \alpha^2\check{Z}_B + \alpha\check{Z}_C}{\check{Z}_A + \check{Z}_B + \check{Z}_C}$$

Under the 2 assumptions made it could clearly be seen that the unbalance in the current of the transformers is due to

(a). The difference in the ratios of transformations and to
(b). The difference in the impedances of the transformers

The total current in the secondary winding of transformer A is

$$I_A = I_0 + I_d = \frac{\check{E}_A'(N_A + \alpha^2 N_B + \alpha N_C)}{\check{Z}_A + \check{Z}_B + \check{Z}_C} + \frac{I_a(\alpha\check{Z}_B - \alpha^2\check{Z}_C)}{\check{Z}_A + \check{Z}_B + \check{Z}_C}$$

$$I_B = I_0 + \alpha^2\check{I}_d = \frac{\check{E}_A'(N_A + \alpha^2 N_B + \alpha N_C)}{\check{Z}_A + \check{Z}_B + \check{Z}_C} + \frac{\dot{I}_a\check{Z}_c - \alpha\,\dot{I}_a\check{Z}_A}{\check{Z}_A + \check{Z}_B + \check{Z}_C}$$

and

$$I_C = I_0 + \alpha I_d = \frac{\check{E}_A'(N_A + \alpha^2 N_B + \alpha N_C)}{\check{Z}_A + \check{Z}_B + \check{Z}_C} + \frac{I_a(\alpha^2\check{Z}_A - \check{Z}_B)}{\check{Z}_A + \check{Z}_B + \check{Z}_C}$$

If we assume that the ratios of transformations of the 3 transformers are equal then

$$I_0 = -\dot{I}_d\,\frac{\check{Z}_A + \alpha^2\check{Z}_B + \alpha\check{Z}_C}{\check{Z}_A + \check{Z}_B + \check{Z}_C}$$

and

$$I_A = \frac{\check{I}_a(\alpha\check{Z}_B - \alpha^2\check{Z}_C)}{\check{Z}_A + \check{Z}_B + Z_C}$$

$$I_B = \frac{\check{I}_a(\check{Z}_c - \alpha\check{Z}_A)}{\check{Z}_A + \check{Z}_B + \check{Z}_C}$$

and finally

$$\dot{I}_C = \frac{\check{I}_a(\alpha^2\check{Z}_A - \check{Z}_B)}{\check{Z}_A + \check{Z}_B + \check{Z}_C}$$

If on the other hand the ratios of transformations are unequal but the impedances are equal in both moduli and arguments then

$$I_0 = \frac{\check{E}_A'(N_A + \alpha^2 N_B + \alpha N_C)}{\check{Z}_A + {}_B\check{Z} + \check{Z}_C}$$

and

$$\dot{I}_A = \frac{\check{E}_A'(N_A + \alpha^2 N_B + \alpha N_C)}{\check{Z}_A + \check{Z}_B + \check{Z}_C} + j\,\frac{I_a}{\sqrt{3}}$$

$$\check{I}_B = \frac{\check{E}_A'(N_A + \alpha^2 N_B + \alpha N_C)}{\check{Z}_A + \check{Z}_B + \check{Z}_C} + \frac{\check{I}_a}{\sqrt{3}}\,\epsilon^{-j\,30}$$

and

$$\dot{I}_C = \frac{\check{E}_A'(N_A + \alpha^2 N_B + \alpha N_C)}{\check{Z}_A + \check{Z}_B + \check{Z}_C} + \frac{\dot{I}_a}{\sqrt{3}}\,\epsilon^{j\,210}$$

In all the preceding it should be kept in mind that I_0 is the circulating current in the transformers due to the unbalance.

Yours very truly,

E. M. Sabbagh (A'28)
(Instructor in Elec. Engg., Purdue University, Lafayette, Ind.)

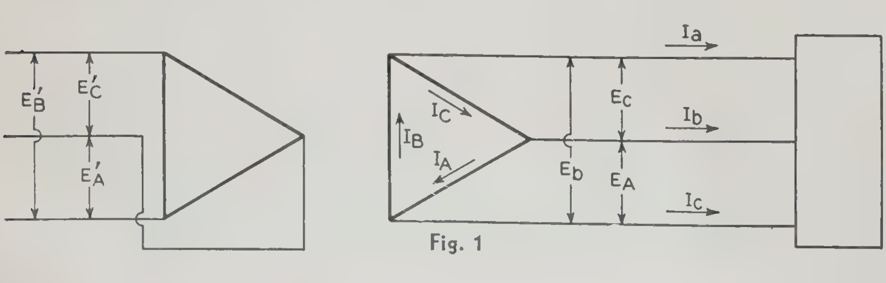


Fig. 1

Operational Calculus

To the Editor:

In my commentary appearing as a "Letter to the Editor" in the December 1934 issue of Electrical Engineering, p. 1681, 2 D operational theorems are given. The first and so-called "transfer" operator is Lagrange's (Oeuvres, volume 3, 1772, page 450) symbolic form of Taylor's theorem ("Methodus Incrementorum," 1717, 1715? page 23). The second theorem (functional derivative of a product) is my own, and I append herewith a crisp derivation of same.

Within the scope of Teixeira's theorem (1900; *q. v.*, "Modern Analysis," Whittaker and Watson, 4th edition, page 131) it is possible to expand one function in terms of another:

$$\phi(t) = \sum_{n=-\infty}^{n=+\infty} A_n[F(t)]^n$$

Consider now the functions $\phi_1(t)$ and $\phi_2(t)$, and the functional operator $\phi_0(D)$. Let:

$\phi_0(D) = \Sigma A_n\epsilon^{nD}$
$\phi_1(t) = \Sigma B_m\epsilon^{mt}$

and with D_i operating on $\phi_i(\ )$ only,

$$\phi_0(D)\{\phi_1(t)\phi_2(t)\} =$$

$$= \sum_{m=-\infty}^{m=+\infty} B_m \sum_{n=-\infty}^{n=+\infty} A_n\epsilon^{m(t+n)}\phi_2(t+n)$$

$$= \sum_{m=-\infty}^{m=+\infty} B_m\epsilon^{mt} \sum_{n=-\infty}^{n=+\infty} A_n\epsilon^{n(m+D_2)}\phi_2(t)$$

$$= \sum_{m=-\infty}^{m=+\infty} B_m\epsilon^{mt}\phi_0(m + D_2)\phi_2(t)$$

$$= \sum_{m=-\infty}^{m=+\infty} B_m\epsilon^{m(t+D_0)}\phi_0(D_2)\phi_2(t)$$

$$= \phi_1(t + D_0)\phi_0(D_2)\phi_2(t)$$

From this result, other interesting and useful theorems are easily derivable.

While in my above referred to communication the unit function appears as $\mathbf{1}_{(t)}$, I much prefer the form $1(t)$ since its nature is that of an ordinary function and not an operator as is sometimes supposed.

Thus:

$$p^{-1}\ \{\phi\ (t)\ 1(t)\} \equiv \lim_{n \gtrsim 0} \int_n^t \phi(t)1(t)dt$$

For a diversity of mathematical and dynamical reasons, I believe my equivalent form:

$$p^{-1}\{\phi(t)1(t) \equiv \int_\epsilon^t \phi(t)1(t)dt$$

where ϵ is a positive infinitesimal of arbitrarily high order, superior to the above. Also, $t\ 0 \lesssim$ should be corrected to $t \lesssim 0$, and my street number is 52 and not 32.

Very truly yours,

I. H. Barkey (A'29)
(Technical Consultant, 2020 52nd St., Brooklyn, N. Y.)

Personal Items

W. F. Wells (A'99, F'12) first vice president and general manager, and a director, of the Brooklyn Edison Company, Inc., Brooklyn, N. Y., retired March 1, 1935, after more than 42 years of service. Mr. Wells studied at Rutgers College, and in 1892 entered the employ of the Edison Electric Illuminating Company of Brooklyn, predecessor of the Brooklyn Edison Company. Several years later he became connected with other companies, which later merged to form The New York Edsion Company, and was associated in the construction of the Waterside generating station, being placed in charge of its operation upon completion in 1901. In 1905 he returned to the Brooklyn company as general superintendent, and in 1913 was elected vice president and general manager and a director of this company and of the Kings County Electric Light and Power Company, these companies forming the Brooklyn Edison Company in 1919. Mr. Wells was a member of the Institute's committee on power stations (now power generation) 1917–19, and took an active part in the work of other societies and organizations.

T. R. Langan (A'13, M'30) since 1931 northeastern district manager, Westinghouse Electric and Manufacturing Company, New York, N. Y., has been appointed traffic manager of the company with headquarters at East Pittsburgh, Pa. Mr. Langan studied at Pratt Institute and at Carnegie Institute of Technology, and was employed by the Westinghouse company in 1904. He engaged principally in electric railway engineering, and in 1919 was transferred to the sales department, becoming manager of the Syracuse, N. Y., office in 1922. Two years later he became transportation manager of the northeastern district, and more recently district manager. Among the important operations with which he has been associated may be mentioned the electrification of the New York, New Haven and Hartford Railroad, and subway and elevated rapid transit train service in New York, N. Y., and Brooklyn, N. Y.

H. P. Charlesworth (M'22, F'28, and junior past-president) assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y., has been reelected as chairman of the board of the Engineering Foundation. He was elected chairman recently to fill an unexpired term as announced in Electrical Engineering for January 1935. Mr. Charlesworth is the Institute's representative on the board. He is also serving the Institute at present as chairman of the committee on Institute policy and a member of the Edison medal and code of principles of professional conduct committees, as well as representative of the Institute on the John Fritz medal board of award. He has also served on other Institute committees, and was a manager 1923–27, a vice president 1930–32, and president 1932–33.

G. H. Bucher (M'24) president and general manager, Westinghouse Electric International Company, New York, N. Y., has been elected a vice president of the Westinghouse Electric and Manufacturing Company. Mr. Bucher is a graduate of Pratt Institute, Brooklyn, N. Y., and has been with the Westinghouse organization since 1909. In 1911 he was transferred to the export department at New York and in 1920 was appointed assistant to the general manager of the Westinghouse Electric International Company. In this company he advanced to the successive positions of assistant general manager in 1921, vice president and general manager in 1932, and president and general manager in 1934.

F. D. Newbury (A'07, F'21) general manager, machinery engineering, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been reelected as a member of the executive committee of the electrical standards committee of the American Standards Association. Mr. Newbury has been a member of the Institute's standards committee since 1919, and was its chairman 1928–31. He also has been Institute representative on the United States national committee of the International Electrotechnical Commission since 1923, and representative on the electrical standards committee of the American Standards Association since 1931. Mr. Newbury has served on several other Institute committees, and was chairman of the committee on electrical machinery for the year 1927–28. He has presented several Institute papers.

C. R. Harte (A'10, M'32) engineer, The Connecticut Company, New Haven, Conn., has been unanimously reëlected chairman of the electrical standards committee of the American Standards Association. This committee, representing 12 trade and technical associations and government departments, is responsible to the standards council of the association for the orderly development of the associations electrical standardization work. Mr. Harte has been a member of the Institute's standards committee since 1923, and was a representative of the Institute on the United States national committee of the International Electrotechnical Commission, 1929–32.

S. L. Nicholson (A'00, F'13) assistant to vice president and general manager, Westinghouse Electric and Manufacturing Company, New York, N. Y., has been reelected as a member of the executive committee of the electrical standards committee of the American Standards Association.

R. H. Tapscott (A'18, F'29, and vice president) vice president, The New York Edison Company, New York, N. Y., has been reëlected as a member of the executive committee of the electrical standards committee of the American Standards Association. Mr. Tapscott was a director of the Institute, 1930–34, and has served on a number of the Institute's committees, and is now chairman of the finance committee, of which he has been a member since 1931. He is also a member of the Institute's executive committee and of the committee on coordination of Institute activities, and since 1928 of the headquarters committee, during 1929–33 as chairman.

Sidney Withington (M'20, F'24) electrical engineer, New York, New Haven and Hartford Railroad, New Haven, Conn., has been unanimously reëlected vice chairman of the electrical standards committee of the American Standards Association. Mr. Withington has been a member of the Institute's transportation committee since 1927, serving as its chairman 1929–31, and was a member of the meetings and papers (now technical program) committee 1929–31.

V. E. Bird (A'13) executive vice president, Hartford Electric Light Company, Hartford, Conn., and president, Connecticut Power Company, has been elected president of the former company. He had been its executive vice president since 1929, and has been president of the Connecticut Power Company since 1933. He was formerly with the Stone and Webster organization, and since 1913 has been with the Connecticut Power Company, which was acquired by the Hartford Electric Light Company in 1922.

C. N. Simpson (M'34) since 1929 chief engineer of the Gatineau Power Company, Ottawa, Ont., Can., has been appointed general manager of the utility. Mr. Simpson is a graduate of the University of Toronto and was with the Northern Canada Power Company and the Abitibi Power and Paper Company before coming to the Gatineau company in 1926. He is a member of the executive committee of the Canadian Electrical Association and of the Professional Engineers of Quebec.

Samuel Ferguson (A'02) president, Hartford Electric Light Company, Hartford, Conn., has been elected chairman of the board of directors of the company. Mr. Ferguson came to the Hartford company as vice president in 1912 after 12 years with the General Electric Company, and became president in 1924. He is a past-president of the Association of Edison Illuminating Companies and a trustee of the Edison Electric Institute.

G. L. Knight (A'11, F'17) vice president, Brooklyn Edison Company, Inc., Brooklyn, N. Y., has been reëlected as first vice president of United Engineering Trustees, Inc., serving until October 1935. Mr. Knight has been Institute representative on the

board of United Engineering Trustees, Inc., since 1933, and served a previous term 1926–31. He has also served on a number of the Institute's general committees.

C. F. Hood (A'20) since 1933 manager of the Worcester, Mass., district of the American Steel and Wire Company, has been appointed vice president in charge of operations. Mr. Hood is a graduate of Purdue University, and has been with the company since 1917.

C. H. Lydall (A'20) Chicago, Ill., North American representative of Merz and McLellan and associated firm of Merz and Partners, London, England, is not a member of the staff of Sargent and Lundy, Inc., Chicago, as stated in the February 1935 issue of Electrical Engineering, page 258, but may be addressed in care of Sargent and Lundy, Chicago.

Gano Dunn (A'91, F'12, Life Member, and past-president) president, J. G. White Engineering Corporation, New York, N. Y., has been elected president of the board of trustees of Cooper Union, New York. Mr. Dunn is well known for his activities in the Institute, having served on many committees as well as 2 terms as a manager, 2 terms as a vice president, and as president, 1911–12.

T. S. Bills (A'31) motion picture sound engineer, formerly with Fox Movietone News, Inc., New York, N. Y., is now in the employ of the Hearst Metrotone News, New York, and is at present in Washington, D. C.

W. L. Knauss (A'31) who has been a student engineer in the testing department of the General Electric Company at Schenectady, N. Y., is now in the refrigeration engineering department at Fort Wayne, Ind.

J. H. Gill (A'12) former president and general manager, Florida Power and Light Company, Miami, is now chairman of the board of the Memphis Electric Company and vice president of the National Power and Light Company.

C. H. Anderson (M'34) former assistant superintendent, Cattaraugus division, Niagara, Lockport and Ontario Power Company, Olean, N. Y., is now superintendent of the Bradford Electric Company, Bradford, Pa.

J. S. Overstreet (A'31) formerly quotation engineer, General Electric Company, Schenectady, N. Y., is now in the cable sales department of the company at Bridgeport, Conn.

J. L. Tudbury (A'28) manager, Salem Electric Lighting Company, Salem, Mass., has been named general manager of the Gloucester Gas Light Company.

J. O. Turner (A'33) is now an assistant engineer in the national park service, U.S. Department of the Interior, with field headquarters at San Francisco, Calif.

F. B. Conlon (A'31) of Philadelphia, Pa., has recently become an engineering draftsman in the office of the electrical engineer, Pennsylvania Railroad, New York, N. Y.

G. W. Mikuls (A'30) formerly with the Pacific Gas and Electric Company, Oakland, Calif., is now with the Shell Oil Company at Long Beach, Calif.

T. O. Zittel (A'34) is now a student engineer with the Bethlehem Steel Corporation, Lackawanna, N. Y.

C. J. Dunn (A'33) is now a valuation engineer with the Westchester Lighting Company, Mt. Vernon, N. Y.

Obituary

Michael Idvorsky Pupin (A'90, F'15, HM'28, past-president and member for life) professor emeritus in active residence, Columbia University, New York, N. Y., died March 12, 1935. One of the leading scientists at the time of his death, he came to the United States in 1874 as a penniless boy intent on securing a higher education, but whose first job was driving mules for a Delaware farmer. Doctor Pupin was born at Idvor, Banat, Hungary (now in Yugoslavia) October 4, 1858. In 1879 he entered Columbia University, and was graduated with the degree of bachelor of arts in 1883. He afterward studied mathematics at the University of Cambridge, England, and physics at the University of Berlin, Germany, holding while in Berlin the John Tyndall fellowship of Columbia University. After receiving the degree of doctor of philosophy at Berlin in 1889 he became instructor of mathematical physics at Columbia University, and adjunct professor of mechanics in 1892. In 1901 he was appointed professor of electromechanics, and 2 years later director of the Phoenix Research Laboratory of Columbia University, a position which he held until he retired from active service in 1929. Doctor Pupin made important contributions to knowledge in a-c theory, the passage of electricity through gases, long distance communication, and other subjcts. In a paper published in 1896 he first described the nature of secondary X ray radiation, and in 1902 he sold patents covering his inventions in electrical tuning, so important in radio broadcasting, to the Marconi Company. Previous to this he had accomplished the rectification of high frequency electrical waves, the description being published in 1899. Rapid X ray photography by the use of a fluorescent screen was invented and described by Doctor Pupin in 1896. The chief invention credited to him is the principle of loading telephone or telegraph lines by lumped inductance, his "loading coils" compensating by their inductance for the capacitance between the 2 wires of the circuit. Doctor Pupin also proposed a rule for the placement of these inductances along the line. In this way transmission over long open wire or cable lines was greatly improved. Doctor Pupin received numerous honors for his work, and was awarded some 18 honorary degrees. Among the medals he received are the Cresson medal of the Franklin Institute, 1902; the Prix Herbert of the French Academy, 1916; the medal of the Institute of Radio Engineers, 1924; the Edison medal of the Institute, 1925; and the John Fritz medal, 1932. Doctor Pupin was a past-president of the Institute of Radio Engineers, a past-chairman of the Engineering Foundation, and a member of many other societies. He was a manager of the Institute, 1892–95, a vice president, 1895–97 and 1901–03, and president, 1925–26, in addition serving on a number of Institute committees. Several books and numerous papers have been written by him, many of his papers having been presented before the Institute.

John C. Barclay (A'03, M'04, and member for life) Montclair, N. J., died August 24, 1934, according to word just received at Institute headquarters. For many years he was in the service of the Western Union Telegraph Company, and was assistant general manager when he left the company in 1910. Born at Greensburg, Pa., April 17, 1856, he became a messenger boy for the Pennsylvania Railroad in 1868. Two years later he became a telegraph operator, working for various railroads until he was engaged in 1875 as an inspector for the Automatic Fire Alarm Company, New York, N. Y. The following year he was employed by the Western Union Telegraph Company at Baltimore, Md., and in 1878 was sent to Chicago, Ill. In 1888, while night manager, he completed a course in dental surgery, but continued in the telegraph company and was appointed electrician of the western division in 1898. Four years later Mr. Barclay was appointed electrical engineer of the entire Western Union system, with headquarters in New York, and in 1903 he was appointed assistant general manager. Mr. Barclay secured several patents covering improvements on telegraph instruments and a type printing system.

William Rawson Collier (F'20) manager, Southern Natural Gas Corporation, Birmingham, Ala., died late in January 1935. He was a graduate of Massachusetts Institute of Technology, class of 1900. For the following 4 years he was senior partner of the firm of Collier and Brown, consulting engineers of Atlanta, Ga., and had charge of the design and construction of a number of power and industrial plants. In 1904 he joined the Georgia Railway and Electric Company, where he was in charge of designing and later of sales. In 1912 the Georgia Railway and Power Company was formed and he became its sales manager, subsequently taking similar duties in subsidiary companies. In 1922 he resigned to

accept a position with the Central Hudson Gas and Electric Corporation, Poughkeepsie, N. Y., and in more recent years he was connected with Dwight P. Robinson and Company, United Gas Improvement Contracting Company, Hall Electric Heating Company, Alabama National Gas Corporation, and Mississippi Public Service Company.

JEROME G. VANZANDT (A'31) San Pedro, Calif., died recently following an automobile accident. He was born at Chicago, Ill., July 22, 1883, and received the degrees of bachelor of science, Purdue University, 1904, and master of science, University of Wisconsin, 1908. He then became an associate professor in the engineering college of the University of Southern California for 2 years, following which he was project engineer for the Southern Sierras Power Company on various projects in California. In 1918 he went to France with the A.E.F. engineers, and engaged in private practice upon his return, being in Chile 1922–27 as a consulting engineer to the Republic of Chile and as a designing engineer with the Braden Copper Company at Rancaugua. In 1927 Mr. VanZandt was employed by the U.S. War Department, engineers office, and was located at Pittsburgh, Pa., and more recently at San Pedro.

FREDERICK W. MCKOWN (A'19) member of the technical staff, Bell Telephone Laboratories, Inc., New York, N. Y., died February 27, 1935. He was born at Irondequoit, N. Y., March 1, 1893. In 1914 he received the degree of bachelor of arts from Williams College, and in 1916 the degree of bachelor of science in electrical engineering from Massachusetts Institute of Technology. Mr. McKown then entered the engineering department of the Western Electric Company, New York, transferring to the development and research department of the American Telephone and Telegraph Company in 1921. Since March 1934 he had been a member of the laboratories. Mr. McKown had been in charge of the transmission rating and quality group of the local transmission development department of the laboratories, where he was concerned with fundamental studies on matters effecting transmission, making important contributions in this field.

HENRY EDISON PHELPS (A'17) member of the technical staff, Bell Telephone Laboratories, New York, N. Y., died on February 21, 1935. He was born at Oxford, Mass., March 15, 1893, and received the degree of bachelor of science from Worcester Polytechnic Institute in 1914. He then went to Purdue University as an assistant and received the degree of electrical engineer in 1916. After another year of teaching electrical machinery design at the university he entered the American Telephone and Telegraph Company at New York as a member of the general engineering department, later entering the development and research department. His work was in connection with the development of toll switchboards and switching systems. In March 1934, Mr. Phelps was transferred to the laboratories.

HARRY HANSON DANSBOE (A'30) electrical superintendent, Atlantic Oil Producing Company, Dallas, Tex., died January 19, 1935. He was born at Dallas October 28, 1889, and was employed at the age of 12 as a messenger boy by the Western Union Telegraph Company. He worked his way through successive steps as operator and lineman, and in 1910 became night manager. In that year he went to California with the Producers Transportation Company, and later was a foreman on the Los Angeles aqueduct construction. After a number of other positions in Oklahoma and Texas, he came to the Atlantic Oil Producing Company as electrical superintendent in 1924.

CHARLES KEWLEY KNEALE (A'23) sound engineer, Warner Brothers Circuit Management Corporation, Philadelphia, Pa., died August 26, 1934, according to word just received at Institute headquarters. He was born at Baltimore, Md., December 27, 1897, and attended Marconi Wireless School, Cleveland, Ohio, and Drexel Institute, Philadelphia. In 1920 he entered the testing department of the Philadelphia Electric Company, and was with this company until 1929 when he was employed by Electrical Research Products, Inc.

JOSEPH C. POTTS (A'32) sales engineer, The Electric Storage Battery Company, Washington, D. C., died February 17, 1935. He was born at New York, N. Y., February 1, 1893, and entered the employ of the company in 1912, becoming superintendent of the assembling plant in 1915 and sales engineer in 1931.

WILLIAM EDWARD AHRENS (A'22) western district plant manager, Pacific Telephone and Telegraph Company, Seattle, Wash., died on January 26, 1935. He was born at Elberfeld, Ind., July 15, 1881, and graduated from the electrical engineering course at Purdue University in 1908. Following graduation he entered the construction department of the telephone company at Seattle, and advanced through the department to the position of plant engineer, which he held until he became plant manager in 1929.

CARLETON MURRAY BROWN (A'15) sales engineer, Westinghouse Electric and Manufacturing Company, Washington, D. C., died February 12, 1935. He was born at Lenox, Mass., October 5, 1889, and studied at Worcester Polytechnic Institute. He then entered the apprentice course of the Westinghouse company, and later the general engineering division, engaging in power house and railway high voltage overhead work for a short time, after which he entered sales engineering.

WILL G. COLE (A'24) construction engineer, Natoma, Calif., died recently according to word received at Institute headquarters. He was born in Allegheny County, Pa., April 4, 1882, and began the study of electricity while working in the electrical departments of coal mines in Pennsylvania and West Virginia. He was employed in plant maintenance by a number of companies throughout the west.

CLAUDE KING (A'30) building superintendent, Memphis Tenn., died February 22, 1935. He was born at Owensboro, Ky., May 9, 1892, and studied electrical engineering through extension courses of the University of Tennessee. For a number of years he was chief engineer of the American Finishing Company, Memphis, and had been superintendent of the Falls Building for the past year and a half.

LEON BASIL BOULAVIN (A'32) meter tester, Brooklyn Edison Company, Inc., Brooklyn, N. Y., died June 12, 1934, according to word just received at Institute headquarters. Mr. Boulavin was born in Russia June 30, 1892, and studied in Russia and at Pratt Institute, Brooklyn, N. Y. He had been employed by the Brooklyn Edison Company since 1930.

Membership

Recommended for Transfer

The board of examiners, at its meeting held on March 21, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Beach, Robin, prof. of E.E., head of dept., Poly. Inst. of Bklyn., N. Y.
Brackett, Byron B., director of radiophone broadcasting, Univ. of S. D., Vermillion.
Horle, Lawrence C. F., consg. engr., 90 West St., N. Y. City.

3 to Grade of Fellow

To Grade of Member

Calvert, John F., E.E., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Eberman, Joseph W., chief electrician, Cerro de Pasco Copper Corp., Morococho, Peru, S. A.
Groves, Wm. M., Jr., plant extension engr., Okla. Southwestern Bell Tel. Co., Okla. City.
Hansson, Edwin, transmission engr., Pa. Water & Pwr. Co., Baltimore, Md.
Kelso, Newton T., fractional hp motor engr., Gen. Elec. Co., Fort Wayne, Ind.
Kimbark, Edward W., asst. in E.E., Mass. Inst. of Tech., Cambridge.
Kramer, Andrew W., Jr., application engr., Gen. Elec. Co., Fort Wayne, Ind.
McFarlan, James P., asst. engr., Union Gas & Elec. Co., Cincinnati, O.
Morrill, Wayne J., engr. in charge of design engg., Gen. Elec. Co., Fort Wayne, Ind.
Moulton-Redwood, W. J., cons. and appraisal engr, 20 Eastdale Ave., Toronto, Ont.
Rifenburg, R. C., division engr., Bklyn. Edison Co. Inc., N. Y.
Schaefer, Edward J., design engr., Gen. Elec. Co., Fort Wayne, Ind.
Skinner, Thomas V. S., special field representative, Westinghouse Elec. Intl. Co., Shanghai, China

Spruce, Allan M., switchgear dept., Gen. Elec. Co., Witton, Birmingham, Eng.
Stansel, Numan R., industrial engg. dept., Gen. Elec. Co., Schenectady, N. Y.
Towner, Orrin W., broadcast engr., Bell Tel. Lab., Inc., N. Y. City.
Tuites, Clarence E., instructor in elec. layout design, Mechanics Inst., Rochester, N. Y.
Vedder, Edwin H., E.E., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Warner, Wilbur W., E.E., Gen. Elec. Co., Fort Wayne, Ind.
Webb, Robert T., instructor in E.E., Wash. Univ., St. Louis, Mo.

20 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Apr. 30, 1935, or June 30, 1935, if the applicant resides outside of the United States or Canada.

Adair, W. G., Southern Bell Tel. & Tel. Co., Louisville, Ky.
Amatneek, K., 792 E. 175th St., N. Y. City.
Ankrom, W. R., Ohio Pwr. Co., Bellaire.
Appleman, W. R. (Member), Marathon Elec. Mfg. Corp., Wausau, Wis.
Baessler, K. H., Calif. Wire Cloth Co., Oakland.
Bagwell, L. R., Caywood Elec. Co., Houston, Tex.
Ballengee, W. R., Texas Oil Co., Fillmore, Calif.
Baluta, R. E., Bklyn. Union Gas Co., N. Y.
Barger, G. K., U. S. Bureau of Fisheries, Seattle, Wash.
Bentley, C., Valley Radio & Elec., Mission City, B. C., Can.
Bergson, S. J., Bklyn. Engg. Inst., N. Y.
Birch, J. A., Endura Mfg. Co., Quakertown, Pa.
Blade, Mary F., N. Y. State Employment Serv., Bklyn., N. Y.
Bleuit, F. S., United Engrs. & Constructors, Inc., Phila., Pa.
Blum, A. R., 10 Rawson St., Albany, N. Y.
Blum, L. E., Barium Products Ltd., Modesto, Calif.
Bohne, W. M., Wells Gardner & Co., Inc., Chicago, Ill.
Bondurant, J. E., U. S. Coast & Geodetic Survey, Washington, D. C.
rakel, O. W., Puget Sound Pwr. & Lt. Co., Seattle, Wash.
Bridgers, J. F., 920 E. 2nd St., Washington, N. C.
Brother Bernard (J. P. Ryan) (Member), Manhattan Col., N. Y. City.
Brown, J. C., Ga. Pwr. Co., Atlanta.
Brown, J. D., 2806 Jefferson St., Baltimore, Md.
Brownell, A. B., G. P. Goode Lamp Co., Cincinnati, Ohio.
Buie, J. M., 2505 Willing Ave., Fort Worth, Tex.
Buttner, C. M., Hunter Fan & Motor Co., Fulton, N. Y.
Callaghan, T. J., Waite & Bartlett X-Ray Co., Cleveland, O.
Carlson, E. T. (Member), Trumbull Elec. Mfg. Co., Ludlow, Ky.
Carlson, W. H., 2124 Vineyard Ave., Los Angeles, Calif.
Carter, J. K., Allen Bradley Co., Milwaukee, Wis.
Caspar, R. B., with M. R. Scharff, Mt. Vernon, N. Y.
Cayce, D. F., James & Co., St. Louis, Mo.
Clemens, H. L., Cleveland Elec. Illum. Co., Cleveland, O.
Cleveland, A. W., Gen. Radio Co., Cambridge, Mass.
Clough, F. P., U. S. North Eastern Penitentiary, Lewisburg, Pa.
Coffman, G.M., c/o George W. Taylor Co., Williamson, W. Va.
Collins, H. L., Hoover Co., N. Canton, Ohio.
Colville, D. A., Wash. Water Pwr. Co., Spokane.
Cook, D. E., Citizens Bank Bldg., Rm. 200, Pasadena, Calif.
Cooper, J. H., with M. R. Scharff, Dobbs Ferry, N. Y.
Cotner, W. W., Cornell Univ., Ithaca, N. Y.
Cox, H. O., 1493 N. Garey Ave., Pomona, Calif.
Craig, R. B., Standard Milk Machy. Co., Louisville, Ky.
Crichton, A. L., Wayne Co., Relief Administration, Wooster, Ohio.
Czyzewski, J. B., Consolidated Film Industries, Palisades Park, N. J.
Danesi, C. M., Brown Univ., Providence, R. I.
D'Aniello, J. P., Postal Tel. Cable Co., N. Y. City.
Davis, R. W., Jr., New Brunswick Public Night Schools, N. J.
Deane, B. T., Essex, Conn.
Deane, J., Deanshaven Devpmnt. Co., Riondel, B. C., Can.
Deardorff, E. R., Bingham Pump Co., Portland, Ore.
Decker, W. C., Du Pont Rayon Co., Richmond, Va.
Dellamonica, L., Box 237, Yerington, Nev.
Deming, H. P., Indianapolis Rys., Ind.
Dieffenbach, P. E., 16 Colony St., West Hempstead, N. Y.
Dix, W. H., Potomac Elec. Pwr. Co., Washington, D. C.
Dixon, H. S., Reclamation Dist. No. 108, Knights Landing, Calif.
Dodge, W. B., Federal Shipbldg. Co., Kearny, N. J.
Doonan, R. E., Elec., Water & Sewage Systems, Winterset, Ia.
Eichhorn, C. W., Am. Transformer Co., Newark, N. J.
Fahnoe, H. H., 364 Jefferson Ave., Sharon, Pa.
Few, E. L. (Member), Carborundum Co., Niagara Falls, N. Y.
Fischer, A. J., Union Wire Die Co., N. Y. City.
Fortin, J. J., Duke Price Pwr. Co., Arvida, Que., Can.
Fulton, R. W., Factory Ins. Assn., Hartford, Conn.
Gaffney, C. J., 2531 W. Wisconsin Ave., Milwaukee, Wis.
Gallmeier, R. A., Gen. Elec. Co., Fort Wayne, Ind.
Galloway, J. H., Jr., A. E. Staley Mfg. Co., Decatur, Ill.
Geiger, W. C., Jr., Penn. R. R. Co., Phila., Pa.
Gere, G. H., Lincoln Tel. & Tel. Co., Nebr.
Gieringer, C. K., Liebel-Flarsheim Co., Cincinnati, Ohio.
Gilly, T. A., Gen. Elec. Co., Bridgeport, Conn.
Gohn, C. T., Westinghouse E. & M. Co., Phila., Pa.
Goldberg, H., Univ. of Wis., Madison.
Gow, R. B., Mass. Inst. of Tech., Cambridge.
Griffiths, F. F., Nassau Collegiate Center, Garden City, N. Y.
Guilford, E. S., Rockefeller Center, N. Y. City.
Guttmann, R., 330 Madison Ave., Albany, N. Y.
Halle, C. E., 1234 N. Prospect Ave., Milwaukee, Wis.
Hammarstrom, B. F., 44 Whitmarsh Ave., Worcester, Mass.
Hanke, G. P., Federal Shipbldg. & Dry Dock Co., Kearny, N. J.
Hardy, R. F., First Boston Corp., N. Y. City.
Harshberger, J. D., El Paso Elec. Co., Texas.
Hartsock, E. E., Columbus Ry., Pwr. & Lt. Co., Ohio.
Hayhurst, G. F., 17 Fairmount Ave., Hamilton, Ont., Can.
Headen, H. V., Dunwoody Industrial Inst., Minneapolis, Minn.
Hearst, B. E., Univ. of Colo., Boulder.
Hedler, C. A., Ponemah Mills, Taftville, Conn.
Henderson, W. A., N. Y. Tel. Co., N. Y. City.
Hilbert, E. E., Wagner Elec. Corp., St. Louis, Mo.
Hill, J. S., Radio Air Serv., Inc., Cleveland, Ohio.
Hilton, R. R., 2033–37th Ave. West, Vancouver, B. C., Can.
Hoehn, W. G., Am. Transformer Co., Newark, N. J.
Hood, J. T., Gen. Elec. Co., Schenectady, N. Y.
Hoover, A. J., Underwood Elliott Fisher Co., Kansas City, Mo.
Horsfall, R. E., Salem Elec. Ltg. Co., Mass.
Hough, W. R., Reliance Elec. & Engg. Co., Cleveland, Ohio.
Hoye, J. P., 20 Orchard Ave., Auburndale, Mass.
Hunt, D. W., Clyde, N. Y.
Itkin, K., 8753–26th Ave., Bklyn., N. Y.
Jacobs, D., 1730 Ocean Ave., Bklyn., N. Y.
Johnson, A. L., Jr., 2224 Prince St., Berkeley, Calif.
Johnston, O. E., U. S. Govt., Fort Peck, Mont.
Jones, T. B., Jr., Carbide & Carbon Chemicals Corp., Whiting, Ind.
Jung, C. L., Hoover Co., Milwaukee, Wis.
Kaufman, R. B., Gen. Elec. Co., Schenectady, N. Y.
Kenline, W. J., Southern Sierras Pwr. Co., El Centro, Calif.
Klein, K. M., Ore. State Highway Commission, Waldoort.
Koellein, C. L., Jr., Conite Engg. & Sales Co., Nashville, Tenn.
Krack, E. J., 2113 Liberty St., Erie, Pa.
LaBelle, E. P. (Member), British Columbia Tel. Co., Vancouver, B. C., Can.
Lamb, A. H., Weston Elec. Instrument Corp., Newark, N. J.
Lastovicka, L. J., 5618 W. 24th St., Cicero, Ill.
Laubenthal, G. J., Todd Shipbldg. & Dry Docks Co., Mobile, Ala.
Lawson, F. C., Hydro-Elec. Pwr. Comm. of Ont., Fraserdale via Cochrane, Ont., Can.
Lees, A. M., Jr., 227 Clinton St., Boone, Ia.
Lehmann, S. G., Ill. Bell Tel. Co., Chicago.
Lipson, M. H., Jandous Elec. Equip. Co., Inc., N. Y. City.
Lockwood, M. D., Gen. Elec. Co., Schenectady, N. Y.
Loeschner, R. C., Salem Depot, N. H.
Louargand, A., Western Pipe & Steel Co., So. San Francisco, Calif.
Luckingham, A. L., Colts Fire Arms Mfg. Co., Hartford, Conn.
Manookin, K. M., W. H. Binty Co., Salt Lake City, Utah.
Manthe, R. H., 307 N. Frances St., Madison, Wis.
Markham, T. C., Jr., Durham Tel. Co., N. C.
Marshment, B. C., Marshment Coal & Ice Co., Detroit, Mich.
Martin, S. A., Columbus Ry., Pwr. & Lt. Co., Ohio.
Martin, T. J., Goodman Mfg. Co., Chicago, Ill.
McCallum, R. E., 1300 No. 46th St., Lincoln, Nebr.
McCalman, J. R., Sparks Grammar School, Sparks, Ga.
McCord, C. M. (Member), Memphis Water Dept., Tenn.
McDonald, D. J., Bell Tel. Co. of Can., Montreal, Que., Can.
McGee, P. A. (Member), Reading Co., Phila., Pa.
McIlvaine, W. D., Jr., Minneapolis-St. Paul Sanitary Dist., St. Paul, Minn.
McKinney, L. H., Detroit Edison Co., Mich.
Mischke, C. A. C., 1508A S. 7th St., Milwaukee, Wis.
Moe, O. B., Commonwealth Edison Co., Chicago, Ill.
Montgomery, W. E., So. Calif. Edison Co., La Canada.
Moore, W. M., Am. Zinz Oxide Co., Columbus, Ohio.
Morris, R. R., R-B-M- Mfg. Co., Logansport, Ind.
Murphy, E. K., Panama Canal, Gatun, C. Z.
Nielsen, A. H., Milwaukee Elec. Ry. & Lt. Co., Wis.
Noecker, T. C., Drifted Coal & Supply Co., Shoemakersville, Pa.
Nolen, M. S., Mo. Relief & Reconstruction Comm., Jefferson City.
O'Fiel, J. C. D., Jr., Independent Exploration Co., Houston, Tex.
Oliver, D. F., Reading Elec. Co., N. Y. City.
Oorthuys, H. J., U. S. Bureau of Fisheries, Corvallis, Ore.
O'Sullivan, G. H., Waterbury Cable Serv. Inc., Bronx, N. Y.
Packard, D., Gen. Elec. Co., Schenectady, N. Y.
Patterson, G. R. (Member), Carnegie Inst. of Tech., Pittsburgh, Pa.
Payne, E., Pub. Serv. Co. of Okla., Weleetka.
Pearson, S. I., Gen. Elec. Co., Schenectady, N. Y.
Pedersen, J. H., Box 231, Gilbert, Ia.
Petscavage, M. J., 152 State St., Kingston, Pa.
Pignolet, L. W., Weston Elec. Instrument Co., Newark, N. J.
Piltch, A., Rim Radio Mfg. Co., Bklyn., N. Y.
Pollastro, J. B., Milwaukee Sch. of Engg., Wis.
Prince, M. A., 60 West St., Bloomfield, N. J.
Quinn, J. A., 250 S. Main St., Pittston, Pa.
Raffill, A. W., Pub. Serv. Comm., Madison, Wis.
Rankin, M. B., Ohio Edison Co., Akron.
Rappel, U. J. (Member), Univ. of Dayton, Ohio.
Reece, J. S., U. S. Navy, New London, Conn.
Reed, C. M., VI, Phila. Elec. Co., Pa.
Ribreau, G., Owner & Tenants Elec. Co., N. Y. City.
Ridenhour, W. L., Univ. of N. C., Chapel Hill.
Ringer, R. L., Jr., Wilson Welder & Metals Co., North Bergen, N. J.
Ritter, H. D., Detroit Edison Co., Mich.
Roberts, J. H., Quality Radio Co., San Diego, Calif.
Robinson, R. A., Carborundum Co., Niagara Falls, N. Y.
Rollman, M. E., Cincinnati Milling Machine Co., Ohio.
Root, C. S., Corp. Dept., State of N. Y., Albany.
Rosebrock, F. H., Jr., with M. Scharff, Mt. Vernon, N. Y.
Rotkin, I., G. Boulitte & Co., N. Y. City.
Rumpanos, G., Tampary Constr. Co., Mobile, Ala.
Russo, P., 389 Congress Ave., Waterbury, Conn.
Rutter, A. R., Westinghouse E. & M. Co., Newark, N. J.
Schell, D. H., Cass City, Mich.
Schumacher, W. C., Gen. Motors Export Co., N. Y. City.
Scott, H. U., with L. W. Driscoll, Durham, N. C.
Seppa, G. E., Box 147, Route 1, Wakefield, Mich.
Seuffert, G. C., RCA Mfg. Co., Inc., Phila., Pa.
Shaver, L. C. (Member), Federal Pwr. Commission, Washington, D. C.
Sherer, H. P., Route No. 2, Waynesburg, Ohio.
Sheridan, J. J., 4389 Martha Ave., N. Y. City.
Shimer, A. J., H. N. Crowder, Jr., Co., Allentown, Pa.
Shore, A. G., 244 E. 20th St., N. Y. City.
Shuster, J. D., Bethlehem Shipbldg. Corp., Quincy, Mass.
Richard, J. D., 206 College Ave., Ithaca, N. Y.
Sidway, C. L. (Member), Westinghouse E. & M. Co., San Francisco, Calif.
Simons, W. D., U. S. Geological Survey, Tacoma, Wash.
Simpson, C. E., TERA Bradley-Polk Counties, Cleveland, Tenn.
Richards, S. R., Zenith Products Co., Salt Lake City, Utah.
Singler, E. L., Ingersoll Steel & Disk Co., Chicago, Ill.
Sizelove, O. J., Jr., Diehl Mfg. Co., Elizabethport, N. J.
Smith, J. K., 2955 Grand Concourse, N. Y. City.
Smith, L. M., Los Angeles Bureau of Pwr. & Lt., Calif.
Smith, R. M., Westinghouse E. & M. Co., Newark, N. J.
Snipes, M. A., Western Union Tel. Co., Denver, Colo.
Sogge, R. C. (Member), Gen. Elec. Co., Schenectady, N. Y.
Speck, R. J., Bureau of Pwr. & Lt., City of Los Angeles, Saugus, Calif.
Sreb, J. H., with M. R. Scharff, N. Y. City.
Stewart, A. C., Central Pwr. Co., Grand Island, Nebr.
Stratton, B., Jr., 1226 No. Marshall St., Milwaukee, Wis.
Stryker, N. U., Jr., Ill. Tool Works, Chicago.
Suprenant, H. A., New Eng. Pwr. Assoc., Shelburne Falls, Mass.
Sutton, E. L., Darwind White Coal Mining Co., Windber, Pa.
Tabler, M. C., Penn. R. R. Co., Baltimore, Md.
Tevlin, H. F., Detroit Edison Co., Mich.
Thorne, B. W., Jr., 1946 W. 22nd St., Los Angeles, Calif.
Trainer, S. W., 1209 N. Jefferson St., Milwaukee, Wis.
Trieste, C. W., Fla. Pwr. & Lt. Co., Miami.
Todd, J. R., Arkville, N. Y.
Tolivar, C. A., Am. Dist. Tel. Co., N. Y. City.
Tucker, M., Chandeysson Elec. Co., St. Louis, Mo.
Turner, J. L., F.E.R.A. Research, Houghton, Mich.

Urquhart, M. D., Broad River Pwr. Co., Columbia, S. C.
Valois, R. F., Consolidated Film Industries, Inc., Fort Lee, N. J.
Verbyla, E. J., 195 Drayer Ave., Waterbury, Conn.
Verdier, W. H., 624 Parkwood St., Grand Rapids, Mich.
Votava, G. E., 1563 Jarvis Ave., N. Y. City.
Wacker, K., Crosley Radio Corp., Cincinnati, Ohio.
Wahlers, F. A., Bklyn. Edison Co., N. Y.
Wall, R. E., Teleweld, Inc., Chicago, Ill.
Walsh, W. J., 1680 Gates Ave., Bklyn., N. Y.
Walter, C. W. P., Ford Instr. Co., L. I. City, N. Y.
Weaver, G. W., Metal Products Co., Los Angeles, Calif.
Welch, D. S., 104 N. Niagara St., Maquoketa, Ia.
Wheeler, E. J., c/o W. C. Steele, Jr., Pasadena, Calif.
White, R. E., Humble Oil & Refining Co., Henderson, Tex.
Whitney, D. C., C. C. C. School, Camp Green, Montpelier, Vt.
Wildermuth, J. L., Jr., State Highway Patrol, Columbus, Ohio.
Wilkens, W. B., Hazeltine Service Corp., Bayside, N. Y.
Wille, A. J., 205-24 110th Ave., Hollis, N. Y.
Williams, P. H., Am. Tel. & Tel. Co., St. Louis, Mo.
Wyandt, B. F., Marsh Foundation School, Van Wert, Ohio.
Zeller, C. J., 144 Elm St., Albany, N. Y.

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Foreign

Bagai, M. M., c/o L. Badri, Dass & Son, Roshanpura, Delhi, India.
Bahadurji, D. J., Thorburn House, Merewether Rd., Bombay, India.
Chatterjee, B. N., Dacca Elec. Supply Co., Ltd., Dacca, India.
Farnhill, E. S., British Thomson Houston Co., Ltd., Coventry, Eng.
Lansdown, L. P., Victoria Falls & Transvaal Pwr. Co., Germiston, So. Africa.
Murti, T. V. R., Indian Inst. of Science, Bangalor, India.
Ramaswami, H. K. S., Seshasayee Bros. Ltd., Trichinopoly, So. India.
Shah, N. A., Municipal Committee, Peshawar City, N. W. F. P., India.
Srinivasachary, R., Seshasayee Bros. Ltd., Trichinopoly, Madras, India.

9 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Eberhard, Jacob J., 525 Grant St., Santa Clara, Calif.
Fennis, A. M., 4266 Old Orchard Ave., Montreal, Que., Can.
Hansen, A. Fred, 2065 1/2 W. 30th St., Los Angeles, Calif.
Ince, Frank Edward, 2282 Yale Ave., Maplewood, Mo.
Jordan, Arthur H., 5729 Chester Ave., Phila., Pa.
Lemen, Foster M., 3009 Seward, Omaha, Neb.
Nessler, Aldo E., Delta Starr Elec. Co., 2437 W. Fulton St., Chicago, Ill.
Phillips, R. M., 20 Garth Rd., Scarsdale, N. Y.
Rasmussen, David, 423 Hickory St., Ridgway, Pa.
Ryden, Eric H., Electrolux Servel Corp., 401 E. 111th St., N. Y. City.
Shelley, William L., 203 Greene Ave., Brooklyn, N. Y.
Shirkey, Charles O., 2433 S. Crawford Ave., Chicago, Ill.
Simpson, Sidney, Deputy Loco. Supt., Eastern Bengal R. R., Kanchrapara, Bengal, India.
Skinner, Dean C., 6014 Walnut St., Pittsburgh, Pa.
Smedley, A. B., 82 Warner Ave., Hempstead, N. Y.
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17 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

A.S.T.M. STANDARDS on ELECTRICAL INSULATING MATERIALS, prepared by Committee D-9 on Electrical Insulating Materials. Oct. 1934, Phila., American Society for Testing Materials. 281 p., illus., 9x6 in., paper, $1.75. This volume brings together all the specifications and test methods for electrical insulating materials which the society has adopted, in their latest approved form. It also contains the latest report of the committee in charge of this subject, discussing the developments of interest during the past year.

AUTOMATIC PROTECTIVE GEAR for A-C Supply systems. By J. Henderson. Lond., Sir Isaac Pitman & Sons; N. Y., Pitman Publishing Corp., 1934. 201 p., illus., 8x5 in., cloth, $2.50. The schemes for transmission line protection which have been used in Great Britain and which have been successful in practice are described briefly but with sufficient fullness to present their principles clearly and to show the details of the various methods of connection.

Course in ELECTRICAL ENGINEERING. Vol. 2, Alternating Currents. By C. L. Dawes. 3 ed. N. Y. & Lond., McGraw-Hill Book Co., 1934. 705 p., illus., 8x6 in., cloth, $4.00. This is an introductory text for students who have some knowledge of direct currents but are unfamiliar with alternating currents. Two chapters are devoted to the fundamental laws of alternating currents and alternating-current circuits, after which the applications of these laws to measurements, polyphase circuits, machinery, and power transmission are discussed. New developments have been included, the chapter on vacuum tubes has been expanded, and a chapter on gaseous rectifiers added.

ELECTRIC POWER METERING, a Textbook of Practical Fundamentals. By A. E. Knowlton. N. Y. and Lond., McGraw-Hill Book Co., 1934. 340 p., illus., 9x6 in., cloth, $4.00. Practical methods of watt hour, reactive, and demand metering, and of telemetering and totalizing, are described and the basic principles that underly them and determine their accuracy and reliability are explained.

FROM GALILEO to COSMIC RAYS, a New Look at Physics. By H. B. Lemon. Univ. of Chicago Press, 1934. 450 p., illus., 9x7 in., cloth, $5.00. This textbook of physics, intended for the use of undergraduate students at the University of Chicago, is designed to stress the source material and phenomena, and to interpret them in nontechnical style.

HANDBOOK of CHEMISTRY. By N. A. Lange, assisted by G. M. Forker and R. S. Burington. Sandusky, Ohio, Handbook Publishers, Inc., 1934. Illus., 8x5 in., lea., $6.00. Nearly 1,300 pages of chemical and physical tables are included, selected for the needs of engineers and industrial and research chemists. Appended to the main work are 247 pages of mathematical tables.

MACHINERY'S HANDBOOK for Machine Shop and Drafting Room. 9 ed. N. Y., Industrial Press, 1934. 1592 p., illus., 7x5 in., lea., $6.00. This handbook aims to provide data frequently wanted by machine designers and builders. Much practical information upon the strength of materials, gearing, bolts and screws, speeds and feeds, fits, screw threads, heat treatment, pipe fittings, etc., is presented.

Les MACHINES ASYNCHRONES à Champs Tournants, à Bagues et à Collecteur. By R. Langlois-Berthelot. 2 ed. Paris, Dunod, 1934. 274 p., illus., 9x6 in., cloth, 63.50 frs.; paper, 53.50 frs. This volume represents the course given at the École Supérieure de l'Électricité, Paris, and constitutes essentially a general method for studying asynchronous machines. An introductory chapter describes the industrial properties of these machines, after which a general theory is developed. A final section on design illustrates the application of the theory.

MODERN ACOUSTICS. By A. H. Davis. N. Y. Macmillan Co., 1934. 345 p., illus., 9x6 in., cloth, $6.00. Sources of sound and their theoretical relations, audiofrequency electrical apparatus, the measurement of sound intensity and frequency, sound analysis, acoustical impedance and sound transmission, sound dissipation and absorption, hearing, noise measurement and suppression, acoustics of buildings, sound recording and reproduction are among the subjects discussed.

PRINCIPLES of MATHEMATICAL PHYSICS. By W. V. Houston. N. Y. and Lond., McGraw-Hill Book Co., 1934. 265 p., illus., 9x6 in., cloth, $3.50. This text is intended to give students who have a thorough knowledge of elementary physics, analytical geometry and calculus, a working knowledge of the fundamental methods of mathematical physics which will enable them to use the more advanced treatises on special subjects.

WHO GETS the MONEY? How the People's Income is Distributed. By W. Rautenstrauch. New York and London, Harper & Brothers, 1934. 99 p., charts, tables, 8x5 in., cardboard, $1.00. This contribution to the discussion of the economic crisis is concerned with the costs of producing the national income and with its distribution. The author ascribes most of our present economic troubles to undue overhead costs in the national industrial plant.

SYMPOSIUM on the OUTDOOR WEATHERING of METALS and METALLIC COATINGS. Washington Regional Meeting, American Society for Testing Materials, March 7, 1934. Phila., A.S.T.M. 113 p., illus., 9x6 in., cloth, $1.50. The material that appears in this volume was presented at a symposium held in Washington in 1934. Five papers, with discussions, are given: outdoor test results on bare and metal-coated ferrous specimens; the harmony of outdoor weathering tests; influence of rainfall and smoke on the corrosion of iron and steel; early interpretation of test results in the atmospheric corrosion of non-ferrous metals and alloys; and galvanic corrosion by contact of dissimilar metals.

CONCISE OXFORD FRENCH DICTIONARY. Compiled by A. Chevalley and M. Chevalley. Oxford (Eng.), Clarendon Press; N. Y., Oxford Univ. Press, 1934. 895 p., diagrs., 8x5 in., cloth, $3.00. This new dictionary presents a vocabulary of nearly 40,000 words covering modern literary and commercial idiom with reasonable completeness and including many technical and industrial terms.

TECHNIQUE of EXECUTIVE CONTROL. E. H. Schell. 4 ed. N. Y. and Lond., McGraw-Hill Book Co., 1934. 231 p., 8x5 in., cloth, $2.00. This book discusses the problems of the executive in his relations with his subordinates and superiors. Methods for securing effective coöperation are considered in detail.

TEILCHENSTRAHLEN (Korpuskularstrahlen). Sammlung Göschen 1083. By H. Mark-Berlin and Leipzig, Walter de Gruyter & Co., 1934. 152 p., illus., 6x4 in., cloth, 1.62 rm. This book aims to provide a simple, yet comprehensive account of present knowledge of corpuscular rays. The experimental methods by which they are produced, the behavior of these forms of radiation, and their importance to the physicist, are set forth.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

General Electric Operations Increased in 1934.—At the March meeting of the board of directors of the General Electric Company, the preliminary results for 1934 were presented, showing orders received amounting to $184,000,000, compared with $143,000,000 in 1933, an increase of 29%, and sales billed of $164,797,000 compared with $136,637,000 in 1933, an increase of 21%. The average number of employees was 49,642 compared with 41,560 in 1933. The total earnings of these employees amounted to $75,227,000 as against $55,287,000 for 1933. The average annual earning increased 14% over 1933. Between March 1, 1933 (the approximate low), and December 31, 1934 (the high), the number of employees on the payroll increased almost 37%, and the total annual payroll rate increased from $47,604,000 to $81,300,000, or 70%. At the end of 1934 there were 196,248 stockholders compared with 188,316 a year earlier.

Westinghouse Business Improved During 1934.—The annual report of the Westinghouse Electric & Mfg. Co. for 1934, recently released, shows a net income earned of $189,562, compared with a net loss of over $8,000,000 during the preceding year. Sales billed for 1934 totaled $92,158,893, compared with $66,431,591 for 1933. Orders received totaled $106,473,226 as against $72,473,117 in 1933, an increase of 47%. Better business was reported by all principal divisions of the company and billings for the year were substantially above 1933. The total, however, was still only approximately 50% of the average in the years preceding the depression. Plants of the company that produce the heavier equipment normally used by the electric utilities have operated throughout the year at a load much lower than the 50% average. While Westinghouse has suffered in common with the entire industry from the severe recession in business activity, according to the report it has been able to maintain and in some directions improve its relative position in the electrical field. The volume of the company's foreign business, obtained through the Westinghouse Electrical International Company showed a substantial increase over 1933, and the profits have been greater than for a number of years. The increase in foreign business has not been confined to any single country, but has been world wide. The consolidated companies disbursed $47,321,400 in payroll payments, and gave employment to an average of 35,281 persons during the year. In 1933 the total payroll was $36,047,031, with an average of 29,980 persons employed. It is believed that unless there is a marked change for the worse, the operations of the company for the year 1935 will show a substantial profit.

U.S. Rubber Appoints C. P. Boone. C. W. Bigbie, sales manager of United States Rubber Products, Inc., wire division, recently announced the appointment of C. P. Boone, at San Francisco, as manager of the company's wire sales on the Pacific Coast.

A New Line Connector.—A new semi-automatic mechanical line splice has been introduced by Connect-O-Line, Inc., 7607 Vincennes Ave., Chicago. Simplicity of construction is a marked feature of the new connector, and the positive grip on the wire is claimed to prevent either solid or stranded cable from turning or slipping. The hexagonal body of the connector is pure copper; the gripping lugs and tightening nuts are made of Everdur. Splices for all sizes of both solid and stranded wire are available.

Trade Literature

Wood Preservation.—Bulletin, 16 pp., "Preservation with Eastman NO-D-K." Outlines various methods of wood preservation and recommendations for different types of construction. Tennessee Eastman Corporation, Kingsport, Tenn.

Mechanical Rubber Goods.—Bulletin, 24 pp. Describes transmission, conveyor belting, rubber hose and other mechanical goods for industrial service; more than 200 items and illustrated with 100 diagrams and photographs. The B. F. Goodrich Co., Mechanical Div., Akron, O.

Electronic Rectifiers.—Bulletin, 4 pp. Describes B-L dry metallic electronic rectifiers and lists many standard applications where conversion of alternating to direct current is involved. Commercial sizes and types available, as well as prices, are included. B-L Electric Mfg. Co., 19th & Washington Ave., St. Louis.

Air Circuit Breakers. Bulletin GEA-1662A, 4 pp. Describes trip-free air circuit breakers for buildings, industrial plants and power stations; 600 volts, 1600–6000 amperes, alternating current; 750 volts, 1600-10,000 amperes, direct current, manually or electrically operated. General Electric Co., Schenectady, N. Y.

Air Filters.—Bulletin F-320-3. Describes the Coppus unit type filter for motor and generator intakes and general commercial and industrial ventilation. Bulletin F-310-2 describes filters for air compressors, internal combustion engines, etc. Coppus Engineering Corp., Worcester, Mass.

X-Rays for Industry.—Bulletin, 42 pp., "Instruments of Precision." Describes X-Ray apparatus for use in industrial and educational laboratories and applications in analysis and structure of materials. Testing machines of various types for fatigue tests of metals are also described. J. B. Hayes, Inc., Urbana, Ill.

Fusion Furnace.—Bulletin, 4 pp. Describes the Barrett fusion furnace for determining the fusing temperature of coal ash. Other uses include such operations as the determination of pyrometric cone equivalents of refractory materials, the study of test pieces of ceramic bodies, heat treating and other laboratory work requiring a high temperature gas furnace for producing heat up to 3000°F. Burrell Technical Supply Co., 1936 Fifth Ave., Pittsburgh.

Industrial Condensers.—Catalog, 28 pp. Includes general engineering data on electrolytic and oil-filled industrial condensers as well as their application to motor-starting, power-factor correction and other industrial uses. Lists a large line of industrial units in which the company has pioneered for many years, and facilitates the selection of proper equipment for any given purpose. Aerovox Corporation, 82 Washington St., Brooklyn, N. Y.

Generator Car Axle Drive.—Bulletin, 6 pp. Describes a compensating car axle drive for motivating lighting generators, air conditioning generators, etc. This drive, available in any capacity, uses endless V-belts and, it is claimed, successfully overcomes truck misalignment while producing a constant flow of power without noise. Installation is possible without jacking up wheels and it is readily accessible for maintenance. The Medart Co., 3500 DeKalb St., St. Louis.

Chain Belts.—Catalog K-1, 54 pp., pocket size. Describes chains and sprockets for power transmission, conveying and elevating. A feature of the publication is a section devoted to practical engineering data, and containing rules and formulas for determining chain size, length, pitch, sprocket diameter and ratios; rules for installation, alignment and operation, lubrication methods, etc. A series of charts and tables illustrate the correct type of chain to use, the horsepower to be transmitted, etc. Baldwin-Duckworth Chain Corp., Springfield, Mass.

Insulation Testers.—Catalog 1400, 32 pp. Describes "Megger" insulation testing instruments—self-contained, portable devices for measuring electrical resistance, especially insulation resistance, having various ranges to as high as 10,000 megohms. Modified types, such as "Bridge-Megger" and "Bridge-Meg" sets, have facilities also for measuring conductor resistance to as low as 0.01 ohm. The catalog describes in detail the principle of operation of seven types of instrument now available. James G. Biddle Co., 1211 Arch St., Philadelphia.

Condensers.—Catalog 127. For manufacturers and engineers. On the use of condensers for power factor correction, motor starting, high voltage circuits, etc. Catalog 128, 16 pp. For service men, distributors, dealers. Lists a wide variety of mica, paper and electrolytic condensers in many capacities, voltage ratings and sizes for general radio applications. Catalog 129 includes a comprehensive listing of standard types of replacement condensers of both paper, dielectric and electrolytic construction. Cornell-Dubilier Corp., 4377 Bronx Blvd., New York.